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Manhattan District History

Book II - Gaseous Diffusion [K-25] Project

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Vol. 2 - Research

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MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 2 - RESEARCH

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FOREWORD

Volume 2 presents an account of K-25 research and development activities, excluding work connected with the special chemicals development program, which is covered in Book VII. The purpose, administration, contractual arrangements, and general theory are discussed, and an account is presented of the development of diffusion barrier, special pumps, and special instruments. This is followed by a description of pilot plant work, chemical and physical studies, safety and security aspects, costs, organization, and personnel. Other phases of the K-25 Project are dealt with in separate volumes of Book II as follows:

Volume 1 - General Features
Volume 3 - Design
Volume 4 - Construction
Volume 5 - Operation

Activities described extend from the earliest OSRD contracts, negotiated in July 1941, for the study of the diffusion process, to 31 December 1946, by which time the basic K-25 research program had been completed, and administrative responsibility passed from the Manhattan District to the United States Atomic Energy Commission.

A number of appendices are attached to illustrate the text by means of tabulations, charts, photographs, file references, documentary exhibits, and a glossary. References indicated by parentheses, as (App. B1), (App. C12), etc., refer to Item 1 of Appendix B, Item 12 of Appendix C, etc. Asterisks refer to the Glossary, Appendix F.

The Summary contains an abstract of every major subject treated

in Volume 2. Paragraph numbers in the Summary correspond to section numbers in the main text.

4 April 1947

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MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 2 - RESEARCH

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SUMMARY

1. Introduction. - Research and development activities directed toward the solution of problems encountered in the concentration of Uranium-235 by the method of gaseous diffusion, comprised primarily, the choice of a suitable feed material, the development of diffusion barriers, process pumps, seals, and control instruments, and the adaptation of this equipment to use in the presence of process gas. Research programs were centered in a number of university and industrial laboratories under contracts administered principally by the Columbia Area Engineer.

2. Contractual Arrangements. - The diffusion method was first seriously considered at Columbia University in 1940. Columbia was subsequently awarded contract OEMsr-106 by the Office of Scientific Research and Development, covering the period of 1 July 1941 to 30 June 1942, the work to be directed by Dr. J. R. Dunning. Contract OEMsr-412 authorized an expanded program under the direction of Dr. H. C. Urey from 1 December 1941 to 30 April 1943. Effective 1 May 1943, the Columbia diffusion studies were placed under Manhattan District contract W-7405-eng-50, and the laboratories came to be known by the code name of "SAM Laboratories." These contracts called for research and development work looking toward the design, construction, and operation of a production plant, and evaluation of the diffusion method in comparison with alternate isotope separation methods. In fulfillment of their major commitments, it was necessary for The M. W. Kellogg Company and the Kellex Corporation also to engage in considerable research and

development work on such subjects as barrier manufacture and properties, corrosion, special chemicals, pumps, valves, and control instruments. In discharging its responsibility as operating contractor for the K-25 plant, the Carbide and Carbon Chemicals Corporation sponsored a number of research activities at the Linde Air Products Company, Bakelite Corporation, Union Carbide and Carbon Corporation, Metals Disintegrating Company, and the Sharples Corporation. Effective 1 February 1945, the basic diffusion process research program was transferred from Columbia University to Carbide under contract W-7405-eng-26. Other principal prime contractors include the Bell Telephone Laboratories, Princeton University, Ohio State University, California Institute of Technology, and the Interchemical Corporation.

3. General Theory of the Gaseous Diffusion Process. - When the fissionable properties of the U-235 isotope were discovered in 1940, the importance of separating it from the non-fissionable Uranium-238 became apparent. A group of investigators at Columbia University attacked the problem by the method of gaseous diffusion. The basic working principle of gaseous diffusion was discovered by T. Graham in 1829, but the K-25 plant represents its first commercial application. The fundamental theory for a practical diffusion separation plant was worked out by Karl Cohen at Columbia. If a mixture of two gases is placed in a container whose walls contain a large number of small perforations, and the vessel is surrounded by an evacuated space, the respective rates of escape of the two components will be in proportion to the respective concentrations, and inversely in proportion to the square roots of the respective molecular weights. Thus, the diffusate will be richer in lighter component than the original gas. In order to prevent the building

up of a back pressure in the outer space, and the continuous decrease of light component concentration and total pressure within the container, a steady state may be maintained by continuously withdrawing enriched diffusate from the outer space, and partially depleted residue from the container, and continuously supplying the container with fresh feed. The K-25 cascade is a repeating series of equipment duplicating this procedure continuously, 24 hours a day. The "outer space" is enclosed by a diffuser, or "converter." The perforated wall is referred to as "barrier." A control valve and two gas pumps are provided to regulate gas flow and pressure, and a cooler removes the heat of pumping. These are the elements of a practical "stage". The K-25 cascade contains 2892 such stages; the K-27 cascade contains an additional 540. In order to prevent ordinary, non-separative mass flow of gas, the size of the barrier apertures should preferably be below the mean free path of the process gas molecules, or on the order of 0.0000004 inch.

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Factors tending to reduce the efficiency of separation are: back diffusion of diffusate, "jostling" (intra-aperture collisions in which light, fast-moving molecules are retarded by striking heavy molecules), non-separative viscous flow, surface film flow, mixing inefficiency (formation of depleted regions immediately adjacent to the up-stream barrier face), pinholes and leaks, and variations in barrier permeability. The gaseous diffusion research program was expanded in December 1942, at which time the Manhattan District requested the M. W. Kellogg Company (which was working under OSRD contract OEMsr-406) to continue its research work and undertake the immediate design of a 1 kilogram per day 90 per cent U-235

gaseous diffusion plant. The Kellex Corporation subsidiary was created to prosecute this work. Fundamental research was to be done at Columbia under Dr. H. C. Urey, with special studies carried on at the Bell Telephone Laboratories, Princeton University, and the Jersey City Laboratories of the Kellogg Company. In early 1942 discussions were held with a group of British investigators regarding fundamental alternative plant designs.

4. Development of Diffusion Barriers. - In the latter part of 1941 the search was begun for a barrier material of the required porous structure, and with suitable resistance to corrosion by UF_6. The first crude samples were tested with UF_6 in 1942, and a method of routine barrier testing was then developed based on the use of mixtures of helium and carbon dioxide as a working substance. The separation factor is defined as the ratio of relative concentration of desired component after processing, to its relative concentration before processing. Relative concentration is the molecular ratio of $U^{235}F_6$ to $U^{238}F_6$ present in the process material. From Graham's law, the ideal single stage separation factor is $\sqrt{352/349} = 1.0043$. The actual separation factor is an increasing function of fineness and porosity of barrier apertures. The porosity of barriers is rated by defining a "permeability" concept as the ratio of actual flow through the barrier, under specified test conditions, to the flow which would occur by molecular effusion if the barrier were not present. Permeability is dependent upon operating pressures, increasing as the difference between fore pressure and back pressure is increased. It is also an increasing function of the number and size of barrier apertures per unit area. Important chemical properties of

barrier include its plugging characteristics (tendency of permeability to decrease with use as a result of UF_6 corrosion products lodging in the apertures) and its consumption rate (tendency to react with and consume the valuable but corrosive process fluid.)

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Ideal considerations call for a continuously decreasing size of diffuser from the feed point to the ends of the cascade. Practical plant design required standardization of a small number of equipment sizes.

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Prior to 1943 many preliminary types of barrier were tested at Columbia. When the university was awarded contract W-7405-eng-50, a division of the SAM Laboratories was established for the specific purpose of studying new barriers.

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These barriers were brittle,

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difficult to handle and manufacture, and poor in resistance to corrosion.

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The product, however, showed an unsatisfactory separation factor. DELETED DOE b(3) Samples examined by Kellex showed good process properties and fair mechanical strength.

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Kellex cooperated, and undertook a survey DOE b(3) of industry to find a company to handle ultimate manufacture.

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A number of other contracts were awarded to outside agencies for special development of critical items.

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In January 1943, a continuous production pilot plant was designed at the Columbia Schermerhorn Laboratory. During the remainder of that year, a steady improvement in the properties of A barrier was effected, but in January 1944, at a meeting of Manhattan District officials with Houdaille-Hershey, Kellex, Carbide, and SAM representatives, plans were made for the immediate conversion of the Houdaille-Hershey plant from A barrier production to K-1 (later known as DA) barrier manufacture. The A barrier was abandoned because of unsatisfactory mechanical properties, and difficult manufacturing problems. At this time responsibility for coordination of all future barrier research was assigned to Carbide.

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The method produced samples which showed good diffusion process properties.

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The DA barrier was studied by E. O. Norris and W. F. Libby at Columbia during the period when emphasis was being placed on A barrier

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development. It was also studied by the Bell Telephone Company and the Kellex Corporation.

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The material was then formed into sheets by passage through a calender. This much of the manufacturing was handled by the Bakelite Corporation.

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This material shows excellent corrosion resistance after fluorination and exposure to UF_6, superior separating efficiency, and good mechanical stability. Moreover, the manufacturing process is comparatively simple.

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WB barrier exhibits a greater plugging tendency than DA, but is capable of very satisfactory reconditioning. Production was carried out by the Linde Air Products Company from January 1945 until March 1946.

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The majority of the stages of the K-25 cascade are fitted with DA barrier; WB has been used in about 50 stages.

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Strenuous efforts were made to utilise domestic powders, and two acceptable varieties were eventually developed, one manufactured by International Nickel at Huntington, West Virginia, and by the Metals Disintegrating Company at

Elizabeth, New Jersey, and the other at the Elizabeth plant using nickel oxide obtained from the Linde Air Products Company at Tonawanda, New York. A third type was subsequently developed and produced by Linde, using an improved process which greatly increased the rate of production.

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It was manufactured by Linde for several months, and will be tested by installation in several stages of the K-27 cascade.

5. Development of Special Pumps. - It was realized in the early stages of the process pump development program that a satisfactory stage pump would have to have absolutely no loss of process gas, very little inleakage of inert gases, no inleakage of oil or condensable vapor, minimum holdup volume, high resistance to corrosion, a wide range of capacity and compression ratio, ability to handle very dense gas, and high efficiency of operation. These requirements could best be met by development of a centrifugal type pump. Ultimate choice was made of a single stage arrangement with overhung shaft, a single triplex seal, and a compression ratio of about 3:1. As produced by the Allis-Chalmers Manufacturing Company, the impeller is built up by welding from plates, rings, and blades of sheet monel, and consists of 20 equally spaced blades which are curved with a backward sweep. The front and

back plates are cold formed in a hydraulic press. The scroll and diffuser are made of internally nickel-clad steel, and all casing joints are welded.

Early pump seal studies at Columbia University were centered around three main types, using, respectively, inert gas, special lubricating oils, and positive contact fluorocarbon polymer sealing rings. The gaseous seal showed greatest promise, and was ultimately selected. An inleaking arrangement was chosen, rather than an outleaking, for reasons of relative simplicity of construction, avoidance of rejection or recovery processes for outleaking process gas, and avoidance of the inherent inefficiency of mixing outleaking process gas streams of different concentrations.

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Various mechanical arrangements were studied at the laboratories of the Ingersoll-Rand Company, Kellex, SAM, and Carbide.

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Later testing and development were carried out at the SAM Laboratories.

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Simultaneously with the development of open-motor centrifugal pumps, various diaphragm types were investigated in order to provide a seal-less design in the event of unsatisfactory performance of the nitrogen-sealed machines. A diaphragm pump was also considered as specially suited for use in the contemplated upper sections of the plant. Gas bearing blower development was prosecuted by Westinghouse and by General Electric in close association with Kellex and SAM. Various designs were studied involving a thin metallic diaphragm in the air gap of the motor. Bearings were lubricated by means of process gas, the motor ran in normal atmosphere, and no seal was necessary. A totally enclosed type was also studied, in which neither a seal nor a diaphragm was required; all parts ran in process gas. This type required special inert lubricating oil and motor insulation.

The density of the gas handled in the purge cascade varies markedly from point to point. Decreasing the density of gas handled by centrifugal pumps decreases their capacity. Positive displacement pumps, however, can handle gases of different densities without this disadvantage. Shaker, paddle, rotary, and magnetic designs were studied, but a reciprocating type was ultimately selected for purge cascade service. A bellows seal was designed with a two inch stroke distributed among six bellows units, each independently supported and constrained by a "Lazy Jack," which was lubricated with fluorinated oil. The piston is lubricated by the process gas, and pump valves consist of

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light sheet metal springs. The purge pumps were manufactured by the Valley Iron Works.

Materials of construction suitable for process pumps were used for the conditioning pumps, but the lightness of the conditioning gas required a very high peripheral speed. Special motors were developed by Westinghouse for 14,400 RPM service. The pumps were provided with two-stage impellers and a disc seal.

For service with process coolant, a vertical pump was developed, to be mounted at the bottom of a surge drum. Pump bearings are lubricated by the coolant. The pump shaft passes up through a tube running to the top of the tank, where a seal permits outleakage of nitrogen confined as a blanket gas under slight pressure above the liquid surface inside the tank.

Early in 1944, Kellex and the Beach-Russ Company started development of a special rotary, oil-sealed mechanical vacuum pump for process gas, of welded construction and with a special seal so as to provide a very low leakage rate. A magnetic oil level indicator was developed, and, for easy access to the interior, welded vacuum joints were designed so that they could be machined or rewelded with relative simplicity. A quadruple shaft seal was provided, and flucrinated seal oil used. A heating system was incorporated for control of oil viscosity, and a cooling system for use at steady operating speeds.

Work was undertaken early in 1944 by the F. J. Stokes Machine Company to develop a special, rotary, oil-sealed, mechanical vacuum pump suitable for fluorine service, and meeting requirements similar to those for the process gas vacuum pumps. Some difficulty

was experienced with the units developed in that the seal oil reacted with highly concentrated fluorine. On the basis of a series of Kellex tests, an operating procedure was worked out in such a way as to obviate this disadvantage.

The K-25 high vacuum pumps must meet requirements for high speed, high capacity, and extremely high vacuum. The system finally developed calls for connecting equipment to be evacuated to a primary pump which discharges to a booster pump, both of which are of oil diffusion design. The gas then flows into a rotary piston, single-stage, high vacuum, oil-sealed fore pump. A refrigerated vapor trap is installed ahead of the primary pump. Development work was carried on at the National Research Corporation, Westinghouse, Distillation Products, Inc., and Kellex laboratories.

6. Development of Special Instruments. - The K-25 instrument program was complicated by such special conditions as the necessity for determining process purity at hundreds of points, the sub-atmospheric nature of operations, the corrosiveness of UF_6, the need for isotopic assay work, and the ultra-sensitivity of the diffusion process to steady state disturbances. The mass spectrometer principle forms the basis of a number of the more important instruments in use at K-25. It is, itself, based on the concept of ionization of gases by electron bombardment, formation of accelerated ion rays by electrical fields, deflection of these rays by a perpendicular magnetic field, and differential bending of the paths of ions of differing masses. The line recorder, working on the mass spectrometer principle, records the concentration of nitrogen, oxygen, hydrogen fluoride, perfluorodimethylcyclohexane, and CO_2-N_2O. Numerous accessories include a Pirani gage for

sample flow measurement, an "adjustable leak" for extremely small flow control, a chemical trap for UF_6 removal, a glass trap for removal of mercury carried from the diffusion vacuum pump, and an ionisation gage for pressure measurement. Used in routine testing of all process equipment prior to placing on stream, the leak detector provides a means for rapidly locating any and all very small vacuum leaks. The method involves playing a jet of helium probe gas over a suspected surface while the equipment is under high vacuum, and detecting the presence of the probe gas in a mass spectrometer type indicator. The assay machine is a modified mass spectrometer used for determining isotopic concentration of process material samples.

The fission counter works by inducing fission in a sample of process material by means of neutron bombardment from a radium-beryllium source. The resultant spurts of positive ions are detected by collection at a grounded electrode, and are proportional, in number, to the U-235 concentration of the sample. Designed for analysis of process gas containing relatively high proportions of impurities (as in the purge cascade), the space recorder effects measurement of total alpha emission, by electrical collection of resultant gaseous ions. Combining this information with the known isotopic composition of the uranium present, the total UF_6 concentration in a mixture of uranium hexafluoride and light diluents can be computed. The thermal conductance cell provides another method for determining the amount of light diluents in mixtures of UF_6, nitrogen, and oxygen. It is based on the principle that an electric current passing through a wire increases its temperature, and that the difference in temperature between the

wire and the gas surrounding it reaches an equilibrium value, which is dependent on the percentage composition of the gas. Since electrical resistance of the wire is a function of its temperature, measurement of this resistance indicates its temperature, and thereby, the gas concentration.

Used in the purge cascade, the acoustic analyzer determines, indicates, and records the volumetric concentration of light diluents in the process stream, and actuates a control mechanism so as to prevent overloading of the purge cells because of increased UF_6 concentration in the process stream being fed to a purge building. The primary element consists of a resonance tube containing a diaphragm at each end. One diaphragm is excited by an electromagnetic coil, and sends sound waves through the gas chamber which excite the second diaphragm and cause it to induce a voltage in a second coil. The sound intensity, and, hence, the voltage induced is greatest at the natural frequency of resonance of the chamber, which in turn is a function of the composition of the process sample gas within the chamber. The HF analyzer utilizes a viscosity bridge which is analogous to an electrical Wheatstone bridge. Long metal capillaries are used as the four resistances, process gas passing through two parallel pairs of "resistors." A differential pressure transmitter and recorder is connected between midpoints of the bridge arms to indicate unbalance. A sodium fluoride trap, which removes HF, is inserted between the two capillaries of one branch. This results in a diminished flow through the second leg of that branch, and unbalancing of the bridge. The degree of unbalance affords an indication of the HF concentration of the sample gas.

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Capable of detecting extremely low UF_6 concentrations, trace indicators were developed to provide a means for monitoring UF_6 concentrations in the atmosphere, vent gases, seal exhaust lines, and purged cells. Trace indicators work by exposing certain chemical reagents to suspected gases, the presence of UF_6 being indicated by a characteristic coloration. The sensitive element may consist of salicylic acid crystals, or absorbent filter paper. The latter type is periodically checked by chemical treatment with potassium ferrocyanide. It may be arranged to provide continuous and automatic trace indication by setting up a moving tape impregnated with potassium ferrocyanide, and allowing a beam of light to pass through the tape and then actuate a photocell connected to a microammeter which measures intensity of light transmission. The infra-red absorption meter is a portable leak detector of special design used for checking coolant lines, coolant tanks, and process coolers. Air samples from the vicinity of suspected coolant leaks are pumped through a test chamber, through which two infra-red beams are passed. One of these beams is also passed through a lithium fluoride filter which absorbs all infra-red radiation. The intensity of this beam will therefore be independent of the coolant concentration in the chamber; that of the other will vary with this concentration. The two beams are focused, respectively, on each of a pair of resistance thermometers connected into a Wheatstone bridge circuit. A difference in temperature between the two thermometers results from the difference in intensity of impingent radiation, and causes a measurable difference in electrical resistance. The dew point recorder was designed to monitor the plant supplies of dry air and nitrogen, and

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to warn of excessive amounts of water vapor in the gas. Intensity of a reflected beam of light from a cold mirror is dimmed by condensation of moisture on the surface. Measurement of the mirror temperature required to prevent dimming of the reflected ray provides indication of the dew point of the sample gas. The differential pressure indicator was specially developed to measure the extremely small flow of sealant nitrogen gas to the process pump seals. It determines the gas flow by electrically measuring the differential gas pressure across an orifice of known dimensions. Variation of the differential pressures is converted, by means of a bellows arrangement, to a movement of the iron core of an electromagnet, thereby inducing voltage changes which are a function of the differential pressure, and thus of the gas flow, to be determined.

7. Pilot Plant Development. -

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A number of pilot plants were subsequently constructed at Columbia University for further study of the process. Pilot Plant No. 1, initially operated in October 1942, was arranged as a twelve-stage total reflux cascade. It was run for over 3200 hours, yielded data pertaining to cascade behavior with A, DA, and WB barriers, and provided operating experience with various types of process equipment and instruments.

On 10 May 1944, Pilot Plant No. 2 was placed in operation, consisting of a six-stage total reflux cascade using reciprocating pumps. It afforded the first opportunity to study the behavior of control instruments and tubular and flat plate designs of A, DA, and WB barriers

under conditions approaching those anticipated in a full scale production plant.

Pilot Plant No. 3 was erected and operated by SAM personnel; Kellex furnished design, procurement, and supervisory services. An eight-stage cascade was set up, using Westinghouse gas bearing blowers and dummy diffusers. Operation on C_7F_{16} was begun on 15 June 1944. The installation was found to be hydrodynamically stable and subject to satisfactory process control, and vacuum-testing and welding techniques were developed. Studies of process gas consumption and blower performance were then made, using mixtures of nitrogen and UF_6.

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In order to obtain performance data for single-stage blower operation, a Westinghouse gas bearing blower was used at the SAM Laboratories in the summer of 1944 to circulate process gas through a set of 45 tubular diffusers. The experiments provided significant data pertaining to blower behavior, corrosion, and barrier plugging.

8. Chemistry and Physics of the Diffusion Method. - From 1940 to 1942 extensive efforts were put forth at Iowa State College, the University of Chicago, and the laboratories of the Ethyl Corporation, to prepare an organic uranium compound suitable for use as a gaseous diffusion working substance, but no satisfactory substitute for the corrosive uranium hexafluoride was found. The corrosion and other chemical problems anticipated with the use of UF_6 led to the establishment of a chemical section at the SAM Laboratories. Study of the physico-chemical properties of UF_6 was begun in 1940, involving methods of handling the

gas, and new ways of preparing it for chemical analysis. Other chemicals studied included nickel and nickel carbonate, barrier materials, and uranium compounds other than UF_6.

The mechanical properties of barriers have been studied by means of bending, tensile strength, rolling, fatigue, and flutter tests involving thousands of routine examinations which were necessary in the course of the barrier development program. The barrier chemistry research program included the development of fluorinating, or conditioning, procedures, and study of methods of minimizing process gas consumption and barrier plugging.

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The techniques were extended to include measurements of barrier porosity, and were also modified to apply to tubular samples.

9. Safety and Security. - Features of the Columbia Area safety program included a safety department and a medical division set up by the SAM Laboratories, and a Safety Advisory Committee with responsibility for anticipating and coping with special safety problems arising. The Columbia Area Engineer supervised contractor safety programs, and maintained liaison with the District Medical and Safety Sections. A Columbia Area Security program was also instituted in accordance with standard Manhattan District policies.

10. Costs. - The total cost of the K-25 research program was $14,073,004 as of the end of the fiscal year 1946, at which time the estimated total for completion of contracts was $15,811,663.

11. Organization and Personnel. - In anticipation of the awarding of contract W-7405-eng-50 to Columbia University, Major B. K. Hough, Jr. was designated Columbia Area Engineer in the spring of 1943. He was succeeded in January 1944 by Captain L. L. Grotjan. The war research activities in nuclear physics at Columbia University were organized under the name of SAM Laboratories. By February 1945, the work and equipment had been transferred to the Kellex Nash Laboratories. On that date responsibility was assumed by the Carbide and Carbon Chemicals Corporation. SAM activities were directed initially by Dr. H. C. Urey, and, after February 1945, by Dr. R. H. Crist. Dr. Urey was aided by Associate Directors, Dr. L. M. Currie, and Dr. H. S. Taylor. Dr. J. R. Dunning directed research and development in mechanical engineering problems, pilot plants, process operations, and isotopic assay methods. J. H. Arnold directed Kellex research and development, and Dr. Manson Benedict had charge of process design, and planned experimental corrosion studies and studies of barriers, cold traps, and other equipment. Other key research personnel include Dr. R. M. Burns (Bell Telephone Laboratories,) Drs. H. S. Taylor and G. G. Joris (Princeton University), Drs. A. E. Gessler and D. M. Gans (Interchemical Corporation), Dr. R. M. Badger (California Institute of Technology), and Dr. A. L. Henne (Ohio State University).

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MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 2 - RESEARCH

SECTION 1 - INTRODUCTION

1-1. Purpose. - K-25 research and development activities were directed toward the solution of problems encountered in the separation of Uranium-235 from natural uranium by the method of gaseous diffusion.

1-2. Scope. - This volume treats of fundamental or pure research and associated laboratory development of materials, equipment, and processes utilized by other branches of the K-25 Project in the design, construction, and operation of the diffusion plant. Research incidental to the performance of these other functions, as differentiated from basic research, is discussed in Volume 5. The fundamental research activities comprised the choice of a suitable feed material, the development of diffusion barriers and auxiliary equipment such as pumps, seals and control instruments, and the adaptation of this equipment to use in the presence of the process gas. It was necessary to solve very serious corrosion problems, and to develop a number of special chemicals. The hazard of corrosion lay not only in the obvious possibility of equipment deterioration, but in the much more detrimental effect of product consumption, which occurs in even mild forms of corrosion that do not reach destructive intensity. The research and development program for special chemicals required by the K-25 Project is described in Book VII.

1-3. Authorization. - Authorization of research was handled

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similarly to other phases of the K-25 Project as mentioned in Volume 1 of this book, and described more fully in Volume 1 of Book I.

1-4. Administration. - Research programs were centered in a number of university, and industrial laboratories, under contract to the Government. In accordance with established Manhattan District practice, contracts (App. D31) were administered by specified Areas of the District. Administration of the majority of the contracts dealing with fundamental K-25 research and development (excluding work on special chemicals) was the responsibility of the Columbia Area Engineer, with the remainder under the jurisdiction of the New York Area Engineer (App. B1). A resume of research and development contracts is presented in Appendix A.

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SECTION 2 - CONTRACTUAL ARRANGEMENTS

2-1. Columbia University.

a. Selection and History of Negotiations. - The diffusion method was seriously considered first by E. T. Booth, A. Von Grosse, and J. R. Dunning of Columbia University in 1940. Since this group already was directly concerned with the diffusion process, it was decided to expand its program under a series of Government contracts. OSRD Contract OEMsr-106 was negotiated with the Trustees of the University to cover the period 1 July 1941 to 30 June 1942, the work to be done under the direction of Dr. J. R. Dunning. Contract OEMsr-412 permitted an expanded program under the direction of Dr. H. C. Urey to be carried on at the University from 1 December 1941 to 30 April 1943. Effective 1 May 1943, the diffusion studies at this institution were embodied in Manhattan District Contract W-7405-eng-50, the work to be directed by Dr. Urey. The laboratories at Columbia came to be known as the "SAM Laboratories". This was a code name meaning "Special Alloyed Materials".

b. Scope of Contracts. - The above contracts provided that Columbia University furnish the research and development work necessary for the design, construction, and operation of the diffusion (K-25) plant, and continue experimentation to a point where certain alternate isotope separation methods could be evaluated. The University was further required to develop special processes, instruments, and materials. The District Engineer also assigned to this contract a number of miscellaneous special studies for which the University

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possessed trained scientific personnel and equipment.

2-2. The M. W. Kellogg Company - Kellex Corporation.

a. Selection and History of Negotiations. - The negotiations leading to the selection of The M. W. Kellogg Company and the ultimate organization of the Kellex Corporation as Architect-Engineer to design, engineer, and procure special equipment for the gaseous diffusion plant are described in Volume 5.

b. Scope of Research Commitments. - In fulfillment of their major commitments, it was necessary for The M. W. Kellogg Company and the Kellex Corporation to engage in considerable research and development work on barrier manufacture and properties, corrosion, special chemicals, pumps, valves, instruments, etc. Though much of this work was done in their own facilities, considerable engineering research and development was performed by other contractors under Kellex sponsorship. These activities are described in Sections 3 through 7 of this volume, and in Volume 3.

2-3. Carbide and Carbon Chemicals Corporation.

a. Selection and History of Negotiations. - The Carbide and Carbon Chemicals Corporation was engaged under contract W-7405-eng-26 to operate the gaseous diffusion plant. Details of selection and negotiations with this contractor are recorded in Volume 5.

b. Scope of Research Commitments. - In the discharge of this responsibility, Carbide sponsored a number of research activities at Linde Air Products Company (Subcontract 2), the Bakelite Corporation (Subcontract 3), Union Carbide and Carbon Chemicals Corporation, (Subcontract 4), Metals Disintegrating Company (Subcontract 5), and at the Sharples Corporation (contract W-7405-eng-143).

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Effective 1 February 1945, the basic diffusion process research program was transferred from the Columbia University contract W-7405-eng-50 to the Carbide and Carbon Chemicals Corporation contract W-7405-eng-26 under Supplement No. 4. The name "SAM Laboratories" was retained by this organization, which continued its work program until 15 March 1946, at which time its facilities, and its remaining work groups engaged in problems of a continuing nature, were moved to the K-25 plant at Oak Ridge, Tennessee.

2-4. Bell Telephone Laboratories (Western Electric Company).

a. Selection and History of Negotiations. - Contract W-7405-eng-142 was negotiated in August 1943 to consolidate and extend, under the Manhattan District, investigations on performance testing, heat treating, and rolling of barrier which were being conducted under OSRD.

b. Scope of Work. -

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2-5. Princeton University.

a. Selection and History of Negotiations. - This contractor was selected because of the experience of Dr. H. S. Taylor, who directed the project work, and because of the existence of certain facilities not available at Columbia University at the time of the negotiations. Technical aspects of the proposed contract were discussed by Dr. Taylor and Dr. H. C. Urey on 25 May 1943, and the contract (W-7405-eng-98) was negotiated on 3 June 1943.

b. Scope of Work. - The Princeton contract required that methods of pretreating nickel barriers, to induce corrosion resistance to process gas, be investigated, because, at the time Princeton began its work, available information regarding pre-hydrogenation and pre-fluorination was decidedly inadequate.

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2-6. Other Research Contracts.

a. Interchemical Corporation. - Under contract W-7407-eng-25, the Interchemical Corporation was engaged to develop methods for the production of nickel powders suitable for use in the Mix type powdered nickel barrier. A pilot plant was constructed to produce powders in twenty-five pound batches for testing and research purposes. The ultimate objective was to adapt and operate an existing Interchemical pigment plant to produce twelve tons of nickel powder per month.

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b. Ohio State University. - The three principal problems assigned to Ohio State University under the Manhattan District contract (W-7495-eng-95) were: (1) Purification of n-perfluoroheptane (Vol. 3), to be used as a standard in establishing specifications for inertness of fluorocarbons to process gas; (2) Preparation of fluorochloro compounds to serve as a starting material for the preparation of polymeric materials inert to process gas; and (3) Investigation of possible preparation of organic liquids which would dissolve process gas and could be cooled to form glasses, these glasses in turn to be used for obtaining the absorption spectrum of process gas.

c. California Institute of Technology. -

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SECTION 3 - GENERAL THEORY OF THE GASEOUS DIFFUSION PROCESS

3-1. History of Diffusion Theory.

a. Importance of U-235. - Immediately after the discovery of nuclear fission* in uranium by the German investigators, O. Hahn, and F. Strassmann (App. D1) in December 1938, the effect was confirmed by other scientists working in various laboratories. Among those to do so were J. R. Dunning and his collaborators (App. D2) in January 1939, at Columbia University. Between this time and March 1940, they completed several research studies which contributed to an understanding of the complex phenomena involved in nuclear fission. On the latter date, they presented experimental evidence (App. D3) establishing a fact already predicted (App. D4) on theoretical grounds, namely, that nuclear fission arises from the presence of the uranium isotope having an atomic weight of 235 and commonly called "U-235". In their experiments, performed with the aid of A. O. Nier at the University of Minnesota, they had succeeded in separating minute amounts of U-235 from naturally occurring uranium. Since this isotope is present only to the extent of 0.71 per cent in natural uranium and its compounds, they concluded that it was important to effect uranium isotope separation on a larger scale for the investigation of chain reaction* possibilities in uranium. Further confirmation of their results was shortly obtained from experiments performed at the University of Minnesota, Columbia University (App. D5), and the General Electric Company at Schenectady (App. D6).

b. Isotope Separation by Diffusion. - The investigators at Columbia proceeded to consider ways of separating the uranium isotopes

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in order to obtain -235, and from the sizeable number of methods previously known or proposed, they selected the gaseous diffusion method. Although this principle was discovered by T. Graham in 1829, the K-25 plant is its first commercial application. This had been one of the first methods attempted for other elements by Aston with partial success in 1913 for neon, and later by Harkins, Hertz and others with more satisfactory results for chlorine, argon, hydrogen, nitrogen, carbon, and other elements. It had been shown that the method was operable in these cases, and it was believed that it could also be applied to uranium compounds. However, the low yield of product per unit of time, and the large quantities required for studying chain reactions, made it imperative that the theory of the diffusion method be re-examined. This was done by Karl Cohen and others at Columbia, their results showing how the earlier experimental procedures for other elements should be modified when applied to uranium. In an important paper (App. D7), Cohen derived the fundamental theory for a gaseous diffusion separation plant. This has been used, essentially unchanged, in the design of the K-25 production plant at Clinton Engineer Works, Oak Ridge, Tennessee.

3-2. Theoretical Principles Underlying Operation.

a. Hypothetical Experiment. - The principle of molecular effusion can be visualized by imagining a closed container, say a rectangular box, containing a large number of very small openings. The box is filled with a gaseous compound, and surrounded by an evacuated space. According to the Kinetic Theory of Gases, the myriads of individual molecules are in a state of ceaseless activity. Each

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molecule travels at high speed in a straight line until it collides either with another molecule, or with a wall of the container. Those which happen to enter one of the apertures in the wall, pass through and escape to the outer space. This amounts to a decrease in the quantity of gas within the container and would be evidenced by a drop in the pressure within the container. If the experiment is repeated with a gas of greater density (higher molecular weight), the result will be the same, except that the rate of effusion will be slower. Measurement in each of the two cases would show that the rates are inversely proportional to the square roots of the molecular weights of the two compounds. The two tests must be run at identical temperatures. Under such a condition the Kinetic Theory states that the average kinetic energy of individual molecules are equal in each case. Since kinetic energy is equal to one half the product of mass times square of velocity, the following equation can be written:

$$\frac{1}{2} m_1 v_1^2 = \frac{1}{2} m_2 v_2^2$$

therefore:

$$\frac{v_1}{v_2} = \sqrt{\frac{m_2}{m_1}}$$

Where v represents average molecular velocity, and m represents molecular mass. The ratio of molecular velocities is the same as the ratio of effusion rates, and the ratio of molecular masses is the ratio of molecular weights. This constitutes, therefore, a mathematical formulation of the experimentally observed phenomenon. A third experiment may now be visualized in which a mixture of two gases of differing density are used. The respective rates of escape will logically be

in proportion first to the respective concentrations, and second to the respective average molecular velocities, hence inversely to the square roots of the molecular weights.

b. Continuous Operation. - As the process of effusion takes place, two changes occur. First the gas escaping into the evacuated space builds up a back pressure, which tends to drive molecules back through the perforated walls into the container. Since the gas which has passed through the container wall (diffusate) is richer in lighter component than the starting mixture within the container, the effect is doubly disadvantageous because a greater proportion of back-diffusing gas will consist of the desired light component than would be the case if this gas contained only the concentration of light component which existed in the starting mixture. This is in accord with the reasoning applied above where respective effusion rates were visualized in proportion to respective concentrations. The second change taking place as the process goes on is a drop in the quantity of gas, and hence of pressure, within the container. This is undesirable because it is this so-called "fore pressure" which motivates the basic process, forcing molecules to flow through the perforated walls to the outer space. This effect is also doubly disadvantageous because, as time proceeds, the concentration of lighter component decreases within the container, and, in proportion, its concentration in the diffusate passing through the wall is decreased. These disadvantages may be obviated by resorting to continuous operation. A "steady state" is set up by supplying raw gas to the container, by withdrawing undiffused, "partially depleted" gas from

the container, and by removing "enriched" gas from the downstream side of the perforated wall, all at constant rates. In this way changes in pressure and concentration are eliminated. Flow rates are adjusted in order to keep desired factors, such as concentration of light component and total pressure within the container, as high as feasible. Similarly back pressure is minimized.

c. Practical Application. - The heart of the K-25 plant is the diffusion cascade, which is essentially a repeating series of equipment duplicating continuously, twenty-four hours a day, the simplified procedure discussed above. The "container" is called a diffuser or converter. The "perforated wall" is referred to as barrier. A control valve and gas pumps are provided to regulate flow and pressure of the gas, and a cooler prevents the heat of pumping from raising the temperature of the operation. These are the elements of a practical "stage". 2892 diffusion stages are provided in the main cascade at K-25. The K-27 facility provides an additional 540. An important consideration is the size of the apertures in the barrier. It is apparent that ordinary "holes" will permit ordinary mass flow of mixed gas through the membrane, without the desired separative effect. It is necessary to keep the diameter well below the length of the "mean free path" of process gas molecules. This is the average distance travelled by an individual molecule between two successive collisions with neighboring molecules. A very efficient barrier would have an aperture diameter of 0.0000004 inch.

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d. Factors Tending to Reduce the Efficiency of Separation.

(1) Back Diffusion. - As discussed above, the back pressure on the downstream side of the barrier must be held at a low value in order to minimize diffusion of diffusate back through the membrane to the upstream side, resulting in separation in the wrong direction.

(2) "Jostling". - Many collisions occur between light and heavy molecules while they are passing through the barrier openings. On the scale of molecular magnitudes, those openings should be viewed as long tortuous passageways through the thick wall of the barrier. Since light molecules flow faster than heavy molecules, collisions in which a light molecule hits a heavy one from behind are more frequent than those in which a heavy molecule hits a light molecule from behind. As a result, heavy molecules ($U^{238}F_6$) are, on the average, speeded up by collisions with light molecules ($U^{235}F_6$), and similarly the light molecules are retarded. The effect of this "jostling" is to reduce the flow of desired component, and increase the flow of undesired component through the barrier apertures. The separation is correspondingly reduced. The inefficiency is less pronounced with smaller ratio of hole size to mean free path of the molecules. The separation factor will therefore improve at lower operating pressures, since under this condition the mean free path is greater. This jostling effect is opposed by the back diffusion effect, which reduces the preponderance of collisions of light molecules against heavy molecules from behind over the reverse type of collision.

[redacted] (3) Viscous Flow. - Some non-separating "viscous"

flow occurs with any practical hole size.

(4) Surface Flow. - A surface flow sometimes occurs along the film of gas molecules which are adsorbed on the walls of the holes. Viscous flow and surface flow are minor effects.

(5) Mixing Inefficiency. - As in most cases of fluid flow, a stagnant film tends to form in contact with the high pressure side of the barrier. This becomes depleted of U^{235} F_6. Additional U^{235} F_6 must diffuse through this film before passing through the barrier. The result is a retarding of the separative action. The effect is minimized by using high gas velocities so that the resulting turbulence will reduce the thickness of the stagnant film.

(6) Pinholes and Leaks. - Pinholes in the barrier and leaks in the converter assembly result in non-separative flow from the high pressure to the low pressure zone. Each converter in the K-25 plant has been tested to keep this leak flow below 2 per cent of the total flow in the "A" stream.

(7) Variation in Permeability. - Variation in permeability from point to point in the barrier causes inefficiency because of inequality of separation. The term permeability refers to the ease with which the gas can penetrate the barrier under given conditions of fore pressure and back pressure. The Kellex Corporation evaluated this inefficiency theoretically in July 1944 in terms of the magnitude of the variations. The theory was used to set specifications for tolerable degree of variability in barrier permeability. For more complete discussion of molecular effusion and design principles, reference should be made to the Kellex Completion Report, Section

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3-3. Work on Process Development. - Prior to the granting of OSRD contracts at Columbia, and during the earlier period of these contracts, experimental work continued, in addition to further theoretical studies. The experimental progress is described in later sections of this volume. It may be stated briefly that mechanical devices and material were in the very early stages of development, with many of the details under investigation. Theoretical considerations had reached a stage where design, construction, and operation of a plant could be fully envisaged. This state of affairs led to the conclusion that the process appeared to be very promising and capable of being operated successfully, and that further research and development should be pursued vigorously.

a. Expanded Research Program. - The incentive for this continued development came in December 1942, when the War Department, represented by the Manhattan District, requested The M. W. Kellogg Company, which was working under OSRD contract OEMsr-406, to continue its research work and to undertake the immediate design of a diffusion plant for the production of one kilogram per day of U-235 at a concentration of 90 per cent. A subsidiary firm, the Kellex Corporation, was created to undertake this work (App. D8). Fundamental research was to be done at Columbia University (App. D9) under the direction of Dr. H. C. Urey (App. D93) with some study of special problems at other places such as Bell Telephone Laboratories (App. D10), Princeton University (App. D11), and the Jersey City Laboratories of The M. W. Kellogg Company. At this time, the gas diffusion work at Columbia was being

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carried on under OSRD contract OEMsr-412, but negotiations for transfer of the work to the Manhattan District were in progress. As tabulated by Fellox, it was recognized that the Project involved:

1. The design of a plant utilizing a process never before attempted on other than a laboratory scale and for which even laboratory data was incomplete.
2. The engineering of an operable diffusion cascade comprising several thousand stages, under conditions which made it apparent that important decisions would have to be made before adequate process data would be available.
3. The construction of a plant of unusual size and complexity containing large quantities of special equipment - the resulting installation having to be for all intents and purposes vacuum tight and surgically clean.
4. The design, engineering and construction of extensive auxiliary facilities and utilities.
5. The development and fabrication of several millions of square feet of barrier - a totally novel and highly special material.
6. The development and fabrication of six or seven thousand special pumps of various sizes and characteristics.
7. The development and fabrication of six or seven thousand highly special pump sealing devices.
8. The development, fabrication and assembly of several thousand converter units of several sizes.

9. The development and fabrication of large quantities of special valves, pipe and other process equipment.

10. The development and manufacture of tens of thousands of special metering and controlling instruments.

11. The development of a comprehensive vacuum technology and of special leak testing devices.

12. The development and production of sizeable quantities of a number of special chemicals of high purity.

13. The solution of unprecedented corrosion problems.

14. The procurement of a large block of variable frequency power of ultra-dependability.

3-4. Design of Large Scale Plant. - Utilizing the theory developed by Cohen, and as a result of further studies by its own engineers, the Kellex Corporation, working under OSRD contract, made a report of progress in March 1943 (~~Smyth 112~~). This "First Progress Report" on the diffusion plant was based on the concepts of stage and cascade operation as discussed in Paragraph 2-3 of Volume 1. Comprehensive process design was included for a large scale diffusional separation plant to produce one kilogram of U-235 per day, 90 per cent pure, from 2109 pounds per day of feed containing 0.71 per cent U^{235} [6]. Design of auxiliary equipment was also presented in considerable detail.

3-5. Alternate Plant Arrangements. - In the early part of 1942, a group of English scientists, including Messrs. W. A. Akers and F. Simon, visited this country and explained their scheme of plant design. The American plant, as developed by the Kellex engineers from the theory of Cohen and others, was planned to operate at relatively

high gas pressure, and hence under conditions of turbulent mixing. It was also designed for minimum barrier area holdup and equilibrium time. The holdup is the amount of diffusing material which it takes to fill up the plant, or that remains in the plant and cannot be withdrawn as product. The equilibrium time is that period during which the plant must operate at total recirculation before a product of the requisite purity may be obtained. If the holdup is decreased, the equilibrium time also decreases. The English plant, however, was devised to operate with diffusive mixing and thus with lower gas pressures than the American plant. While there are advantages to both schemes, the American engineers rejected the British design primarily because of the large gas volumes required in the latter. Several other alternative British designs were considered but they too were rejected because of the large pumping loads and complicated equipment required. These are described in detail in the British publications (App. D13). On a later visit by Messrs. F. Simon, R. Peierls, and other members of a British group, alternative plant designs were again discussed, and similar conclusions were reached by the American investigators (App. D14). Further discussion of British assistance in connection with design problems is presented in Volume 3, Section 15.

S-C. Later Work on Plant Theory. - The theoretical group at the SAM Laboratories continued its study of the large scale plant, attention being centered mostly on problems of control and stability of operation. The results have been presented in several reports (App. D15). These workers also investigated the behavior and operation of the 84 stage pilot plant (a portion of the main production plant) erected

at Clinton Engineer Works, Oak Ridge, Tennessee, and devised a program of experiments planned to test the operating theory (App. D16).

[redacted]

SECTION 4 - DEVELOPMENT OF DIFFUSION BARRIERS

4-1. Early Studies. - In the latter part of 1941 the search was begun for a barrier material of the required porous structure and with suitable resistance to corrosion by uranium hexafluoride. When the first crude barriers were tested with UF_6 in 1942, the separating efficiency observed left much to be desired. Since very little work had been done on gaseous diffusion theory prior to the K-25 Project, the phenomena involved were not well understood. It was not known whether the inefficiency of the early separations obtained was due primarily to fundamental characteristics of the molecular effusion process, or to imperfect design and construction of the barriers employed. To avoid the difficulties and inconvenience of handling UF_6, it was decided to carry on routine barrier testing with a working substance consisting of a mixture of helium and carbon dioxide. It then became necessary to determine the relationship between the experimental results obtained with a particular barrier when separating helium from carbon dioxide, and the separative efficiency which would have been obtained with the same barrier under the same conditions, but using the K-25 working substance, i.e., a mixture of U-235 hexafluoride and U-238 hexafluoride. Discouragingly slow progress was made in working out such a method of correlation, as well as in the development of a basic understanding of phenomena involved. In the fall of 1942, when the first plant design calculations were made, barrier development had been in progress at Columbia University for over a year under OSRD contracts. It was clear that considerable improvement in barrier properties was to be expected,

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but, in order to proceed with plant design, it was necessary to fix, at that time, certain specifications (App. D94) for the barrier. Subsequent development was then directed toward meeting or exceeding these specifications.

4-2. Barrier Properties.

a. Process Properties.

(1) Separating Efficiency. - The most important property of the barrier, as far as plant design is concerned, is the separating efficiency, the effectiveness of "filtration" of $U^{235}F_6$ molecules from process material. The "separation factor" is defined as the ratio of the relative concentration of desired component after processing to its relative concentration before processing. By relative concentration is meant the molecular ratio of $U^{235}F_6$ to $U^{238}F_6$ present in the process stream. The "single stage separation factor" would be based on the ratio of the concentration of the A stream leaving a converter to the concentration in the material stream supplied to the converter. The "overall plant separation factor" would be based on the ratio of concentration of the product material to the concentration of feed material supplied to the plant. It follows from Graham's law, that the ideal separation factor α for a single gaseous diffusion stage is the square root of the ratio of the molecular weight of $U^{238}F_6$ to the molecular weight of $U^{235}F_6$:

$$\alpha = \sqrt{\frac{m_2}{m_1}} = \sqrt{\frac{352}{349}} = 1.0043$$

In practice, with other variables such as operating pressure and temperature fixed, the actual single stage separation factor is a function of

barrier structure, increasing with the fineness and uniformity of the apertures. If the separation factor realized with the actual barrier is lower than that chosen for plant design, either the desired product concentration cannot be reached, or a lower output will have to be accepted. To produce one kilogram per day of uranium at a concentration of 90 per cent of the light isotope, as originally planned, the separation factor would have to equal or exceed that specified. In June 1944 a minimum separation factor of 2.3 was specified when testing with a mixture of helium and carbon dioxide, at a fore pressure of 50 centimeters and a back pressure of 4 centimeters of mercury. It was not until June 1944, by which time the erection of process buildings at the K-25 plant site was half completed, and the installation of equipment well under way, that a satisfactory theory of effusional separation was evolved, together with a satisfactory method of conversion from helium-carbon dioxide to UF_6 separation factors. This data came as a result of intensified and combined efforts of the SAM, British, and Kellex groups, as well as the California Institute of Technology.

(2) Porosity. - The next most important property of the barrier is its porosity. Of all the gas molecules striking the surface of a barrier at a given instant, only a small portion passes through to the other side. The fraction of total impinging molecules which succeeds in penetrating the barrier wall will depend upon a number of variables including the fore pressure, back pressure, nature of the process gas, and structure of the barrier. It is important to establish a porosity concept which will have a definite mathematical value, which will be convenient to measure, and which will be readily

reproducible under specified test conditions. Such a concept is necessary in order that numerical comparisons may be made between various types of barrier under consideration, and so that the flow rates and pressure drops to be expected in a plant designed to use a particular type will be subject to numerical prediction. In the early stages of barrier development, it was customary to rate the flow characteristics of experimental barriers in terms of the "specific flow", which was calculated by dividing the observed flow rate per unit area by the pressure differential causing it. A given barrier specimen would show widely different specific flows when tested with different gases. Further, the specific flow had to be expressed in a complicated unit such as cubic centimeters per second per square centimeter per centimeter of mercury. To correlate data obtained in different laboratories, it was necessary to convert all values reported to the same system of units. A more convenient concept was later established by incorporating into the specific flow a factor containing the molecular weight and absolute temperature. The new quantity was termed "permeability", and can be thought of as the ratio of actual flow to the flow which would occur by molecular effusion if the barrier were not present. It is a dimensionless quantity; the numerical value is independent of the units employed for flow and pressure so long as the system is consistent. A further advantage in the use of the permeability concept instead of the specific flow is the fact that its numerical value is much less dependent upon the nature of the process gas used, particularly at low pressures. Finally, the permeability as above defined has a theoretical basis in simple molecular effusion theory. For these reasons, the permeability,

designated by γ, was generally adopted throughout the Project for correlating barrier porosities. Further studies showed that the permeability of barrier is made up of two parts. One part (γ_o) is nearly independent of the gas used, and the test conditions of pressure and temperature. The second part is definitely a function of these variables. Thus, it was found that when observed permeability was plotted against "pressure sum" (fore pressure plus back pressure), a nearly straight line was obtained which could be represented by the equation:

$$\gamma = \gamma_o [1 + S(P_i + P_o)]$$

in which:

γ = permeability
Pi = fore pressure
Po = back pressure
γ_o = extrapolated value of permeability at zero pressure sum
S = the "slope factor"

The porosity properties of a barrier can be specified by giving values for γ_o and S.

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Barrier Type	γ_{16}	S
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Permeability is dependent upon the operating pressure, increasing in magnitude as the difference between fore pressure and back pressure is increased. Permeability is also a function of barrier structure, increasing both with the number and size of the holes. A barrier of a certain permeability with a large number of fine apertures will show a greater separation factor than one with a smaller number of larger holes. It is necessary to specify both upper and lower limits for permeability, since if the permeability rises above the upper limit, or falls below the lower limit chosen for plant design, process pump efficiency decreases. Process pumps become unstable if their intake falls below a specified limit, and as permeability increases, either the horsepower of the process pumps must increase, or the total pressure of the plant must decrease.

b. Chemical Properties.

(1) Plugging Characteristics. - The barrier must be chemically inert to uranium hexafluoride, a very aggressive substance. Reaction of the barrier material with process gas can lead to serious reduction in permeability by growth of reaction products within the pores. Moreover, corrosion at other points in the process system can form solid products which may lodge in the apertures and produce the same result. Since six months was considered to be the minimum allowable life from the point of view of replacement and plant maintenance, a tolerable plugging rate for barrier was set at 0.16 per cent per day.

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(2) Process Gas Consumption. - A second aspect of corrosive action is its inherent consumption of valuable process material. This would be particularly undesirable in the higher sections of the plant, and constitutes a second reason for developing a barrier which is chemically inert to UF_6.

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c. Mechanical Properties. -

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It is difficult to calculate the stresses encountered and set up within the material during operation, but development studies have shown that the substance will be sufficiently rugged if it can be designed and fabricated in such a way as to withstand the rather severe stresses imposed during manufacture and installation. The area of barrier required for the plant was estimated to be five million square feet. It was thus apparent that the fabrication of barrier called for a material which would be both available in suitable amounts, and amenable to as simple a manufacturing procedure as possible which would result in uniform quality.

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4-5. Barrier Size and Shape. - The ideal plant as demanded by theory cannot be realized in practice. In such a plant, for example, diffusers, pumps, and other equipment should theoretically decrease in size continuously from the feed point to the ends of the cascade. Practical plant design requirements called for a small number of equip-

ment sizes, and lowest possible plant cost with respect to this factor and other variables. The distribution of barrier surface throughout the plant is described in Volume 3.

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In order to control the quality of product as far as leakage of barrier tubes is concerned, a "leak flow test" has been devised in which representative tubes selected at random are placed in a special test machine and subjected to internal air pressure. The pressure is adjusted till the rate of flow of air diffusing through the barrier is 300 cubic centimeters per minute, and the upstream pressure is measured.

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4-4. Barrier Types.

a. First Types Studied. - During the early period of the work at Columbia (prior to 1943) many proposals for barriers were investigated and abandoned for various reasons.

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When contract W-7405-eng-80 became effective, a division of the SAM Laboratories was established for the specific purpose of studying new barriers. During this period, many attractive products were developed, some to a greater extent than others.

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It soon became apparent that there were many promising barriers which deserved exploitation, but shortages of manpower, difficulties in procurement of materials, the necessity for rapid development, and similar factors determined the particular types to be selected for further study.

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The properties of some of the barriers were very promising, but most were eventually discarded for reasons to be cited.

b. Principal Types Considered. - In the original plant design report (App. D12), three principal types of barriers were under consideration (App. D17).

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More extensive discussion of barrier development is given in the Kellex Completion Report, Section III, (7).

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/ Some work on the development of production methods was also done by Sam Tour, Inc. under a Kellex subcontract.

(2) Powder Nickel Barriers. -

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This work was started under OSRD contract OEMsr-1125 (App. D19), and continued under contract W-7405-eng-142 (App. D20).

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Samples examined by Kellex personnel toward the end of that year showed good process properties and fair mechanical strength.

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The Kellex Corporation cooperated and supplied some of the technical personnel for this installation. Kellex also undertook a survey of industry to find a company to handle the ultimate manufacture of this barrier. On 1 April 1943 the Houdaille-Hershey Corporation was approached by Kellex and Army representatives.

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It was decided to build a new plant adjacent to the Houdaille-Hershey Oakes Products Plant in Decatur, Illinois. A research laboratory was also organized in part of the Oakes building to supple-

ment the Columbia program.

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A number of contracts were awarded to outside agencies for study of some of the more critical items.

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DELETED This, in turn, was superseded by the DA barrier (formerly called K-1) which was actually used in the K-25 production plant.

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These earlier experiments were made in collaberation with the C. O. Jelliff Manufacturing Company under subcontract 511.146 to contract OEMsr-412 (App. A).

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c. A Barrier. -

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(2) Production. - Laboratory production of this barrier in sizes up to 8 by 14 inches, and in amounts up to fifty square feet per week, was obtained in the Pupin Laboratory of Columbia University

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during the latter part of 1942 and the early part of 1943. In January 1943, steps leading to the continuous production of this material were taken by planning for pilot plant production in the Schermerhorn Laboratory at Columbia University. The design and construction of the necessary machines was undertaken by the New Jersey Machine Company (App. D21), with the cooperation of engineers from the Kellex Corporation. Construction of the machines began in February 1943, and by 1 May 1943, installation and erection of the pilot plant was well under way. Initial operation of the machines was started in July 1943, and the plant eventually operated on a twenty-four hour basis.

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At the termination of contract OEMsr-412 (30 April 1943), it appeared likely that this barrier could be produced in suitable quantity and acceptable quality. Simultaneously

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with the construction of the Schermerhorn Pilot Plant, because of the urgency of the Project, design and construction of machines for large scale production ~~was~~ were carried forward at the Garfield Division, Houdaille-Hershey Corporation, Decatur, Illinois (App. D22). Close cooperation between the groups at Decatur and the Columbia investigators was maintained during this period.

(3) Mechanical Properties. - There was a steady improvement in the properties of the A barrier, especially during the latter part of 1943. However, its mechanical properties were difficult to control, and considerable research on these problems was undertaken.

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report on the A barrier by Edward Mack, Jr. (App. D23) provides complete details of the product as finally obtained.

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The latter is described in succeeding paragraphs.

(4) Abandonment of A Barrier. - At a meeting held at Decatur, Illinois, on 16 January 1944, attended by representatives of the Manhattan District, the Houdaille-Hershey Corporation, the Kellex Corporation, the Carbide and Carbon Chemicals Corporation, and the SAM

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Laboratories of Columbia University, plans were made for the immediate conversion of the Houdaille-Hershey plant from the production of A barrier to K-1 barrier (App. D24, E1).

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Much of the A procedure and equipment at Decatur was directly applicable to the new barrier; hence previous experience and research could be utilized. On the basis of these considerations, major emphasis at the SAM Laboratories was immediately shifted to DA barrier, and research on A barrier was completely discontinued within a few months. It was also decided at this meeting to assign overall responsibility for supervision and coordination of all future barrier research and development to Carbide. Supervision of production and control at Decatur was vested in an engineer on loan from the Bakelite Corporation. A liaison group of Carbide technical men was assigned to the Kellex office in New York. This group reviewed all reports on barrier development materials proposed for manufacture at Decatur, and was responsible for deciding which materials should go into the Decatur plant for processing, which were unsuitable, and which should be further developed.

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e. DA Barrier.

(1) Procedure. - The early history, as well as the inventor of the DA barrier (formerly called K-1 barrier), are matters of some uncertainty; studies of these points are now being made by the Manhattan District Advisor on Patent Matters. The material was known to E. O. Norris and W. F. Libby, at Columbia, during the period when greatest emphasis was being placed on A barrier. It was also investigated at the laboratories of the Bell Telephone Company and the Kellex Corporation.

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(2) Production. - As indicated previously, in the early part of 1944, work on the A barrier at the SAM Laboratories was terminated, and the facilities and personnel available were diverted to study of the DA barrier. The Schermerhorn Pilot Plant at Columbia was altered to produce DA material, and an intensive study of optimum standard manufacturing processes and evaluation of process variables was initiated. To expedite progress, the Kellex Corporation likewise operated a pilot plant at the Nash Building in New York for research on the DA barrier, with the work of both plants coordinated.

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The process, as operated by the Houdaille-Hershey Corporation in Decatur, eventually attained a daily output of 35,000 tubes of DA barrier.

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On 1 September 1944, Kellex personnel and the pilot plant formerly located in the Nash Building were transferred to the SAM Laboratories. On 1 January 1945, the Schermerhorn DA barrier pilot plant was dismantled. The major part of the research had been accomplished, and from then on, attention was centered on another type of barrier. In the main K-25 cascade, plain DA barrier has been installed in 1962 stages.

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f. NB Barrier. - An account has been given, of the

powdered nickel barrier as studied at the Bell Telephone Laboratories and at the SAM Laboratories, first by Columbia and later by Carbide.

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Its separating efficiency was the highest observed in the porosity range of interest, both separating efficiency and porosity being readily controllable and reproducible.

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In January 1945, production was started by Linde and continued through March 1946 at which time the barrier plant was placed in standby condition.

(1) Procedure. - The pilot plant development of this material, was assigned to the SAM Laboratories, was begun during the latter part of 1944, and was continued through May 1945.

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(3) Production. - The WB barrier, which was produced at the Linde plant, was used in a small portion of the K-25 production plant. It was first installed in six stages, and later in forty-eight additional stages which were selected for experimental operation and proof of its suitability.

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5. Minor Types.

They contracted with the Globe Union Company who worked

on the problem for several months.

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The development was not considered promising, and was therefore stopped.

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(3) Y-Barrier. - During the spring and summer of 1944, specimens of pre-formed barrier tubes designated as "Y" tubes were produced by the Beutex Corporation under the sponsorship of the Kellex Corporation.

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In order to establish the feasibility of producing the Y tubes in volume, the A. S. Campbell Company undertook a program of research and development.

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4-5. Powdered Nickel. -

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Eventually, two other varieties were shown to be suitable. One called powder B, or "Virginia" powder, was made by the International Nickel Company at Huntington, West Virginia, and by the Metals Disintegrating Company at Elisabeth, New Jersey; the other,

called C or "Elgin" powder, was made at the Elizabeth plant from nickel oxide obtained from the Linde Air Products Company at Tonawanda, New York.

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Subsequently, another nickel powder, called D powder, was developed and produced by Linde using an improved process which greatly increased the production rate.

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The product possessed the advantages of a continuous manufacturing process, it required only a short furnacing time, and it employed the previously unsatisfactory domestic powders which were readily available.

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T sheet was accordingly placed in production at the Linde plant in February 1946, and continued until the plant was placed in stand-by condition several months later.

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SECTION 5 - DEVELOPMENT OF SPECIAL PUMPS

5-1. Process Pumps. - One of the basic elements of a diffusion stage is a suitable pump or pumps. With the sole exception of the barrier development program, the decisions made in connection with the choice and evolution of process pump sizes and characteristics had a greater effect on the shaping of K-25 cascade design than any other single factor. An extensive treatment of the development of pumps for process use and other purposes can be found in Section III, (8) of the Kellex Completion Report.

a. Requirements. - In 1941 E. A. Beorse prepared a paper discussing the general problem of gaseous diffusion plant pumps (App. D27). It was recognized that the following requirements had to be met:

1. There must be effectively no loss of process gas from the system. The volume of gas to be handled by the pumps, most of which is repeatedly recycled throughout the plant, is very large in comparison with the rate of feed to the cascade or the rate of product withdrawal. The smallest fractional loss of the process stream as outleakage would constitute a very serious loss in terms of feed or product.
2. Inleakage must be limited to a very low tolerance set by considerations of end product loss and purging capacity.
3. There must be absolutely no inleakage of oil fog or

condensable vapor. Such material would react with the process material, and would impair barrier performance.

4. In order to reduce the plant equilibrium time to as low a value as possible, holdup volume of the pumps must be minimized. This amounts to the requirement of very high pumping speeds.

5. Materials of construction must be particularly resistant to uranium hexafluoride, because pump parts are subjected to higher gas temperatures and velocities than any other part of the plant. Corrosion will hasten failure of thin metal parts such as a bellows, and solid corrosion products can interfere with proper performance of precision parts.

6. A wide range of capacity and compression ratio is required.

7. The pump must be capable of handling a gas of unusually high molecular weight; the density of UF_6 is about twelve times that of air.

8. Efficiency of operation is especially desirable in order to minimize the power demanded by the several thousand process pumps.

b. Selection of Pump Type. - It was generally believed (App. B12) that centrifugal pumps satisfied these requirements more completely than any other type, but bellows-sealed reciprocating pumps were regarded as probably acceptable substitutes if the anticipated development of a centrifugal type should prove unsuccessful. The ad-

vantages of a centrifugal machine over a positive displacement type are:

1. It can be built in larger capacities.
2. Holdup volume is lower per unit capacity.
3. It can operate at lower suction pressures.
4. The centrifugal pump has no valves and presents fewer mechanical problems.
5. Delivery of a centrifugal pump is non-pulsing.

However, the centrifugal pump also possesses certain disadvantages:

1. Pressure delivered and pumping capacity vary with gas density, and therefore with the composition, pressure, and temperature of the process stream.
2. There is a pumping limit, or minimum suction volume, below which instability or surging develops.
3. The high speed requirement results in high velocity process gas scouring of the impeller and casing.
4. The pump is affected by small changes in speed.
5. A compression ratio unusually high for centrifugal pumps is required.

Reciprocating pumps were considered desirable in the upper sections of the cascade because of the low pumping speeds required, and prior to the successful development of an external seal for centrifugal pumps, or alternately, internal motor bearings and seal, reciprocating pump development was believed necessary as insurance against possible failure of the centrifugal pump program. Considerable work was therefore done on reciprocating pump development (App. D28, D29), but, since the decision was later made to cancel plans for the construction of the upper

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A.C. OPEN MOTOR CENTRI

WITH CARTRIDGE SEAL

THIS IS THE TYPE ULTIMATELY DEVELOPED FOR PLANT USE

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EN MOTOR CENTRIFUGAL PUMP
WITH CARTRIDGE SEAL
LY DEVELOPED FOR PLANT USE

FIG. 1

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sections, and since the centrifugal pump program proved highly successful, this type of pump was never used in the main cascade. However, a reciprocating type was used for the purge cascade (Par. 5-5).

c. Centrifugal Pump Development. - The work was divided into two portions: the design of the pump proper (impeller, diffuser, and casing), and the design of either a shaft seal suitable for use with the usual separate motor, or the design of a motor to be enclosed within the pump casing and of such nature as to withstand exposure to the process material. Ultimate choice was made of the special seal rather than the totally enclosed arrangement. This decision was based on such disadvantages inherent in the closed type as larger size, complexity, and necessity of auxiliary pieces such as an oil pump, cooling fan, and internal seal. Difficulty was also experienced with the development of special insulation and lubricating oil. Furthermore, delivery schedules for the manufactured items were alarmingly long. In the early stages of the process pump program the decision was made to limit the number of shaft seals to one per unit, thereby specifying an overhung shaft. It was also decided to use a single stage pump design. This required a compression ratio of from 2.3 : 1 to 3.2 : 1 - extremely high for a centrifugal pump. This decision also made necessary the use of peripheral impeller velocities in excess of the velocity of sound. As finally manufactured (App. D36) by the thousand at Milwaukee, Wisconsin, by the Allis-Chalmers Manufacturing Company (Fig. 1), the pump includes an open-type electric motor, and a triple-disc seal. The development of the seal is discussed in Paragraph 5-2. The impeller is built up by welding from plates, rings, and blades of sheet monel. The front and

back plates are cold formed in a hydraulic press. The blades are provided with edge tongues which project into holes in the plates. Except in the 1200 cubic foot per minute size, four "equalizing tubes" pass through the impeller to balance the pressure on both sides and eliminate end thrust. The impeller consists of twenty equally spaced blades of 1/8 inch monel sheet. The blades are curved, and are assembled on the impeller wheel with a backward sweep. They are enclosed at back and front by monel hub and cover discs. The backward sweep feature of the blades gives a steep pressure-volume characteristic, lowers the pumping limit, and provides a non-overloading power-input characteristic. The scroll and diffuser are made of internally nickel-clad steel. All casing joints are welded; all bolts, stays, etc. are provided with welded or soldered seal caps. Bearings are sleeve type, babbitt-lined, fed with continuous flowing lubricant from a central system. At the motor end of the drive shaft there is a flexible coupling, with a removable spacer long enough to permit removing the seal cartridge without disturbing the shaft or motor. A "blowout preventer" (used only during seal maintenance) is provided to prevent leakage of air into the pump while changing the seal. Nearly 6000 of these pumps are installed in the K-25 cascade system.

5-2. Centrifugal Pump Seals.

a. Early Studies. - The Columbia investigators devoted considerable effort to the development of centrifugal pump seals and, as summarized in February 1943 (App. D31), three main varieties were being contemplated.

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b. Selection of Seal Type. -

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d. Development of Mechanical Construction.

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Each of these types possessed certain disadvantages, and none was finally accepted for use in the gaseous diffusion plant. For a discussion of the work on these types the reader is referred to the Kellex Completion Report, Section III, (8) A.

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SCHEMATIC REPRESENTATION

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The basic operation of the seal assembly is simple.

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Design principles and operating characteristics were found to be such that the seal adequately met the requirements for centrifugal stage pumps.

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Investigations were continued at the SAM Laboratories through March 1946, simultaneously with the production program.

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e. Further Refinement of Seal Design. - With the start-up of gaseous diffusion plant operations, a host of problems were encountered having to do with pump seal operation and maintenance. These problems did not easily lend themselves to solution, and soon grew to assume major importance because of the threat of critical delays in K-25 production. Only after a great deal of research and trial were seal troubles reduced to their present low rate of incidence. Carbide carried on technical pump and seal work at the plant site, and also maintained a seal development group at the SAM Laboratories, whose sole aim was to conduct research and improvement studies, and carry out tests on seals developed by Carbide and other agencies. The Kellex Corporation continued research at the Jersey City laboratory, and joined Carbide in the work at Oak Ridge. The Allis-Chalmers Manufacturing Company also collaborated with both Carbide and Kellex in pump seal development, as well as working independently on the problem. At the conferences held on this subject during the period where seal difficulties were of paramount concern, a number of additional valuable suggestions were made by the construction contractor, the J. A. Jones Construction Company.

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A variation of this pump, which retained the same seal unit, was tried, but with no better success. The concensus of all agencies concerned was that a re-design of the pump seal would be required, if efficiency were to be attained in operation. A liaison group, composed of Carbide engineers, was assigned to guide this work to successful completion. The group was to receive suggestions for re-design from all agencies, correlate them, and pass them on to an engineering group which would prepare the design. Testing of new designs was carried out by the Seal Development Group at SAM, and by the Kellex Corporation at the Jersey City laboratories.

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Much of the material embodied in the suggestions for re-design was the result of the experience gained at the plant site with seals during early operations in the experimental building (Vol. 5).

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DOE b(3)

The Allis-Chalmers Company provided the seal bellows and gasket which was used on the seal.

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(2) Prevention of Seal Rusting. - This new seal was a great step forward, but it was not the final answer to pump seal trouble. Original shipments of seals were found to be rusted on arrival at the plant site. Study was made of this problem by Allis-Chalmers and Carbide. After a number of attempts, a solution was worked out so as to prevent any deterioration of the seal between the time it left the manufacturer and its arrival at the K-25 plant. When the seals were ready for shipment, they were cleaned to specifications and packed in silica gel, in an atmosphere of dry nitrogen, and the individual containers sealed. This ended the rust difficulty. In addition, the entire seal was shipped as a cartridge, and was so kept until ready for assembly on a pump.

(3) Improvement of Seal Gasket. - Trouble with seals in the plant continued to be the major cause of cell down-time through the completion of the 306 Section, and for some time during the operation of that section. One major phase of the problem was run down by the Operations Technical Group at the plant. A number of leaks which had been attributed to seals were found to be due to the gasket used on the seals, and not to the seal itself. A new gasket developed by Carbide at SAM has eliminated this trouble. This new part is a rubber ring gasket and is more economical to manufacture and to use.

(4) Seal Modifications for the 306 Section. - Soon after the 306 Section went on stream it became apparent that seal failures were occurring at such a high rate as to reduce the effectiveness

of the upper part of the cascade to a dangerous minimum. Operation of the whole cascade with reasonable economy of production required utilization of the 306 Section, but seal failures in excess of 200 per month posed a serious problem.

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These studies resulted in the production of a seal designated as L-7, which satisfactorily met all of the requirements for cells in the 306 Section. After their installation, an immediate drop of frequency of seal failures was noted, and the rate consistently improved. At the present time seal failure stands at less than 5 per cent of its earlier rates.

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(5) K-27 Seals. -

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They were very thoroughly tested by the group at SAM before being installed. The success of these seals is witnessed by the fact that the rate of seal failure in K-27 stands at a very low incidence. The operating stream efficiency of the cascade has been over 99 per cent, as opposed to the 87 per cent originally predicted in design. In large measure this high efficiency is due to the very thorough research and testing carried out by the Carbide Seal Development Group at SAM.

5-5.

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Diaphragm pumps require no seals, and, therefore, neither a seal gas system nor a seal vacuum system. At the same time, the motor windings can be situated in the atmosphere, so that conventional insulation can be used.

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a. Preliminary Tests. -

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b. Development. -

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c. Types Considered. -

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b(3)

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DOE b(3)

5-4. Totally Enclosed Process Pumps. - The Type CS-CS pump represented a small totally enclosed two-stage Westinghouse design with an oil lubricated bearing and an oil seal. The rotating elements were mounted on a single short rigid shaft. The assembly could be short-coupled and flange-mounted, and required no base plate or foundations. It did require a special motor insulation resistant to process gas, and a special UF_6- resistant lubricating oil. It also required a cooling fan and a special type accessory oil pump. Serious difficulties were encountered with the oil and insulation, and with the dissipation of heat. Development of enclosed motor design was discontinued with the successful evolution of the open-motor sealed unit.

5-5. Purge Pumps. - The purge cascade may be considered as an extension of the main process cascade. Multi-stage diffusional separation is carried out in this section based upon the same gaseous diffusion principles as in the rest of the plant. The pupose at this point, however, is not to effect the separation of different isotopic varieties of uranium hexafluoride, but rather to remove any light diluents which may have found their way into the process stream. The

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density of the gas handled in the purge cascade varies markedly from point to point. The molecular weight varies from that of nitrogen (28), to that of uranium hexafluoride (352). Decreasing the density of gas handled by centrifugal pumps, decreases the discharge pressure, and thereby the capacity. This results in the requirement of higher speed, larger impellers, or more stages. These required characteristics vary from stage to stage. Positive displacement pumps, on the other hand, can handle gases, of different densities without a detrimental effect on the compression ratio. The program which was undertaken to develop the machines which would be necessary for the purge cascade, and which might also serve as acceptable alternates for the main cascade in case a suitable centrifugal pump could not be found for that application, was concerned with the problems of internal inertia of high speed pumps, and minimization of holdup volume.

a. Alternate Types Considered. - Brief description is presented of the four main alternate types of positive displacement pumps which were studied for application in the purge cascade. None of these was finally chosen for the reasons noted below.

(1) Shaker Pump. - The shaker pump, investigated at Massachusetts Institute of Technology, showed early promise. It consisted of a loose piston inside a cylinder which oscillated in an axial direction. The pump required no liquid lubrication, and no seals, since there were no piston rods, but it did require flexible gas inlet and outlet connections. Shaker pump development was abandoned when it was decided that the many problems involved would require an inordinately long time for solution. The interrelationship between piston

weight and stroke, speed, and work done made proper control for varying conditions quite difficult. The valve inertia problem was also serious.

(2) Paddle Pump. - Design work in the paddle type machine was done by the American Machine Defense Corporation (App. A) under subcontract with Columbia University. The pumps consisted of an oscillating paddle travelling on a curved cylinder. The paddle was mounted on external trunnions, and the paddle rod was sealed by a metallic bellows. The paddle did not have to rely upon pressure against cylinder walls for guidance, a large piston displacement could be obtained with only small bellows deflection, and bellows life was long; but the unit was complex and required various bearings, cranks, connecting rods, rockers, etc. The paddle was deformed by large inertia forces. A great amount of development work would have been required to adapt this pump to large scale use.

(3) Rotary Compressor. - The "Roots Blower" is a modified rotary compressor with external gears and bearings, and two figure "8" impellers. No internal lubrication is needed, since there are no rubbing surfaces. Leakage is not objectionable through the few thousandths of an inch clearance between cam and housing because pressures handled are generally low. The "Elliott-Lysholm" rotary compressor retains the advantages of the Roots type, but has greater efficiency because compression is more nearly adiabatic. Helical impellers are provided, and discharge and inlet parts are at opposite ends of the casing. In May 1944 the Elliott Company was asked to determine the feasibility of a 500 cubic foot per minute model. That company proposed carbon contact, bellows-supported seals to be cooled

with nitrogen. Two seals were to be used at each end of the rotor, the space between being filled with seal gas. Oil seals were to be provided at the gear casings. Further work on the rotary compressor was discontinued in August 1944 because of such disadvantages as the requirement of four seals, and the long time necessary for a complete development. Furthermore, at this time the status of reciprocating pump development was evidently satisfactory.

(4) Magnetic Pump. - This type represented a development of a rodless piston pump without the defects of the shaker pump. A magnetic piston, encased within a non-magnetic, thin-walled cylinder, was made to oscillate by means of an external mechanically oscillated electro-magnet. The pump required neither seals nor flexible leads. Important problems involved had to do with development of a suitable magnet, internal lubrication, and equalization of magnetic side pull on the piston. In order to provide gas film lubrication, a rotary motion was given to the piston by adding a three phase induction motor section at the top of the piston. An experimental model was built at the SAM Laboratories in July 1942, using a magnet supplied by the General Electric Company. Tests showed that at 400 RPM inertia forces pulled the piston away from the magnet and caused it to strike the cylinder heads. Development was discontinued, since it was felt that the pump was too massive in relation to its capacity.

b. Choice and Development of Reciprocating Pump. - The reciprocating type pump was ultimately chosen for use in the purge cascade. Original development was done by the American Machine Defense Corporation, and production was handled by the Valley Iron Works. 132

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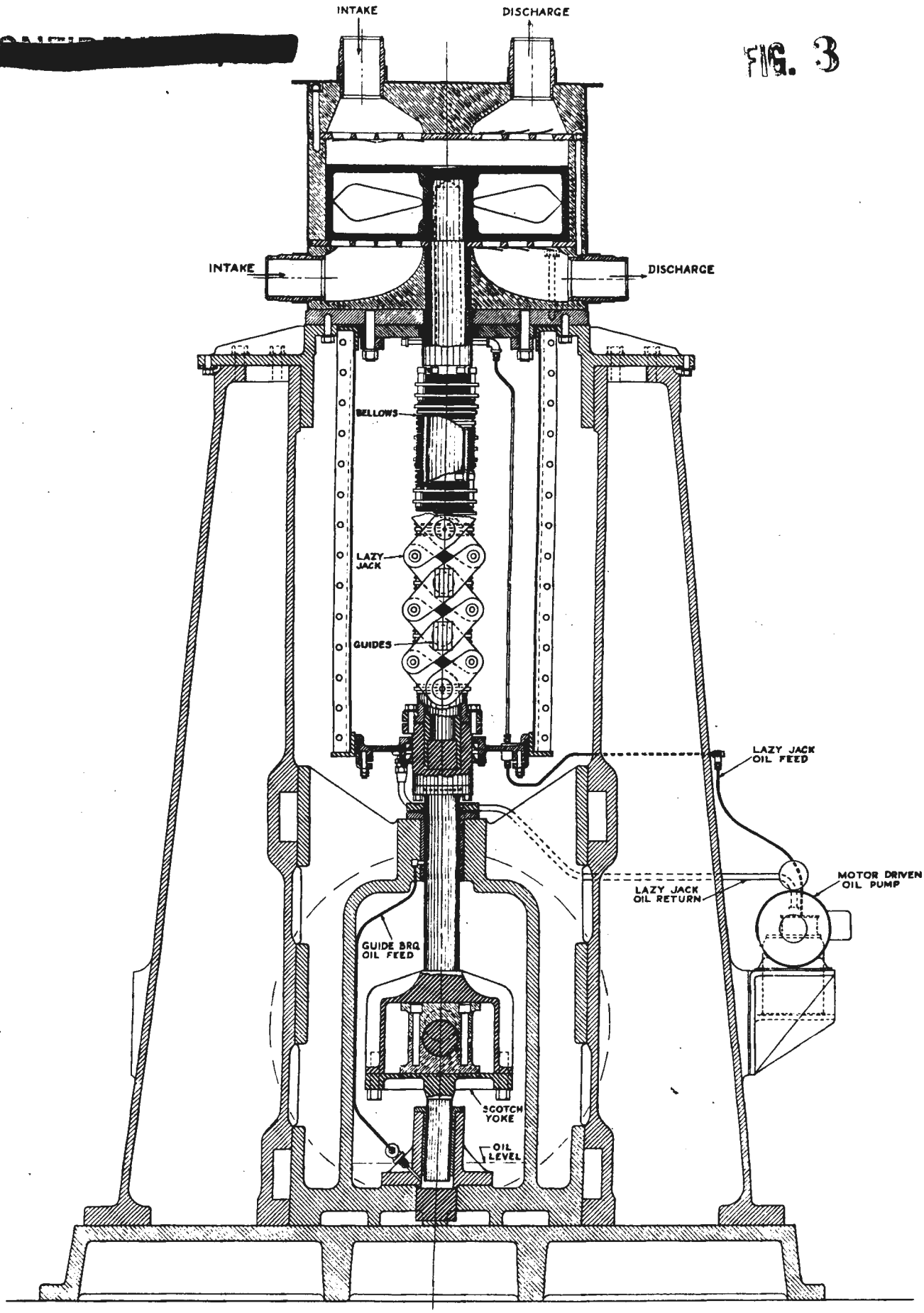
FIG. 3



BELLOWS SEALED RECIPROCATING PUMP.

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VALLEY IRON WORKS

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reciprocating stage pumps are installed in the purge cascade. This pump possessed advantages over the types mentioned above in addition to the relative simplicity and ease of construction. The amount of development work required to work out the detailed design was considerably less than would have been required with one of the more specialized types. The entire pump design (Fig. 3) was very greatly influenced by the type of seal chosen.

(1) Seal. - A bellows type seal was selected. Other methods were considered such as the use of a long, straight, heavy-walled rubber tube. The only rubber which showed a possibility of being sufficiently resistant to attack was butyl rubber, but its mechanical properties were entirely unsatisfactory. A carbon seal was developed which called for a stuffing box of much simpler design than the bellows arrangement. The sealing material was compounded from carbon and a special highly fluorinated organic polymer. The material was found to be seriously subject to chemical attack by process gas, but might be suitable for use at concentrations below one mol per cent of UF_6. Interest in the carbon seal was greatly diminished when it was found that by reducing the design speed from 1000 to 750 RPM, the life of the bellows seal would be so greatly increased that seal replacement would no longer be a great problem. To insure a reasonable length of life, the stroke was limited to 1/3 of an inch per bellows unit. The maximum tolerable unsupported length of piston rod was taken as 24 inches, which allowed the use of six bellows units. The total pump stroke was therefore set at two inches. To counteract the destructive forces set up by inertia waves, each bellows unit was arranged to be independently

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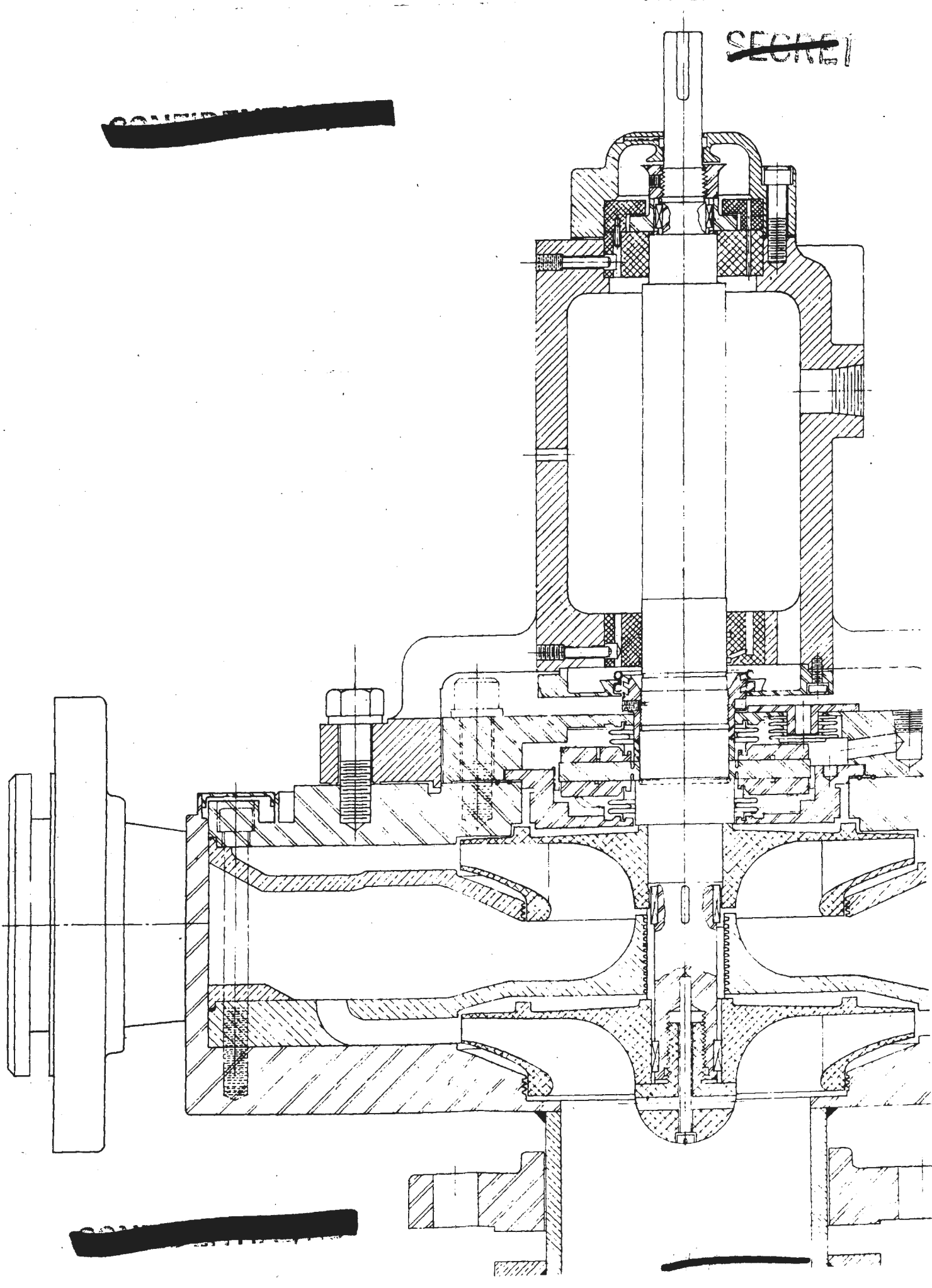

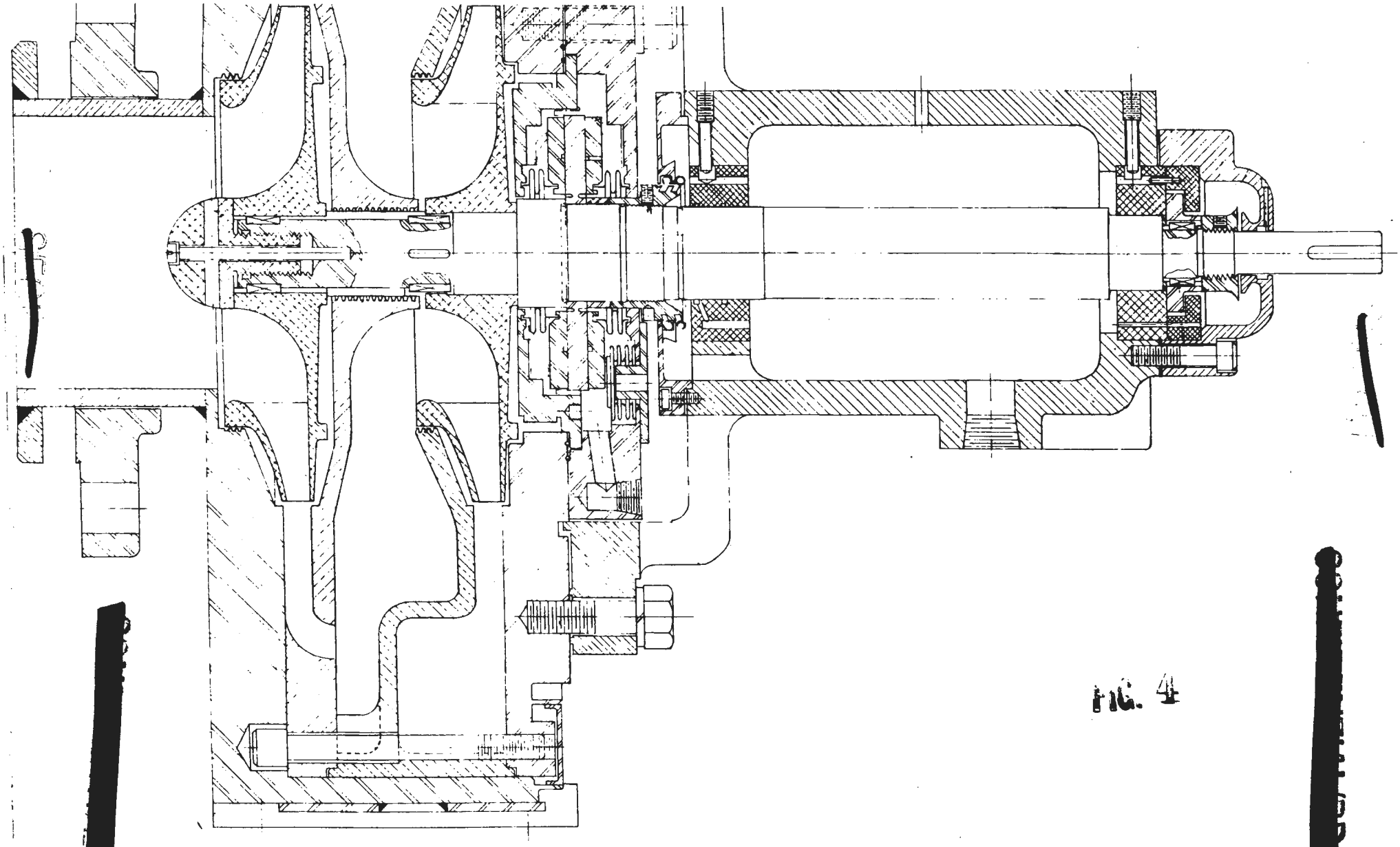

FIG. 4

ELLIOT CENTRIFUGAL CONDITIONING PUMP

supported and constrained to move a certain distance by means of a pantograph or "Lazy Jack". To avoid the possibility of reaction of process gas with oil, a fluorinated oil (C-2144) was used to lubricate the lazy jack. The bellows were made of phosphor bronze.

(2) Valves. - Large valve area and light valve action were required for satisfactory volumetric efficiency. Leaf valves were chosen consisting of light sheet metal springs clamped at one end and operating over slotted valve parts.

(3) Lubrication. - Process gas serves as lubricant. To minimize leakage of gas past the piston, a clearance of 0.005 inches was chosen and proved satisfactory.

5-6. Conditioning Pumps. - The conditioning pumps (Fig. 4) are used to circulate nitrogen-fluorine mixtures at elevated temperature through the converters prior to installation. Materials of construction suitable for process pumps were also used for the conditioning pumps. Conditioning gas is much lighter than process gas, and a peripheral speed was required far in excess of that suitable for process pumps. Two stage impellers were necessary, both stages being equipped with diffusers. A rotary speed of 14,400 RPM was specified, and special motors were developed by Westinghouse for 3 phase, 240 cycle current. A disc seal is provided, but since leakage requirements are less severe than with the process pumps, only one rotary and two stationary discs were necessary. Tightness was attained through the same construction technique used elsewhere at K-25. No inleakage was permissible, but outleakage specifications were less stringent than in the case of process pumps. The pumps were manufactured by the Elliott Company.

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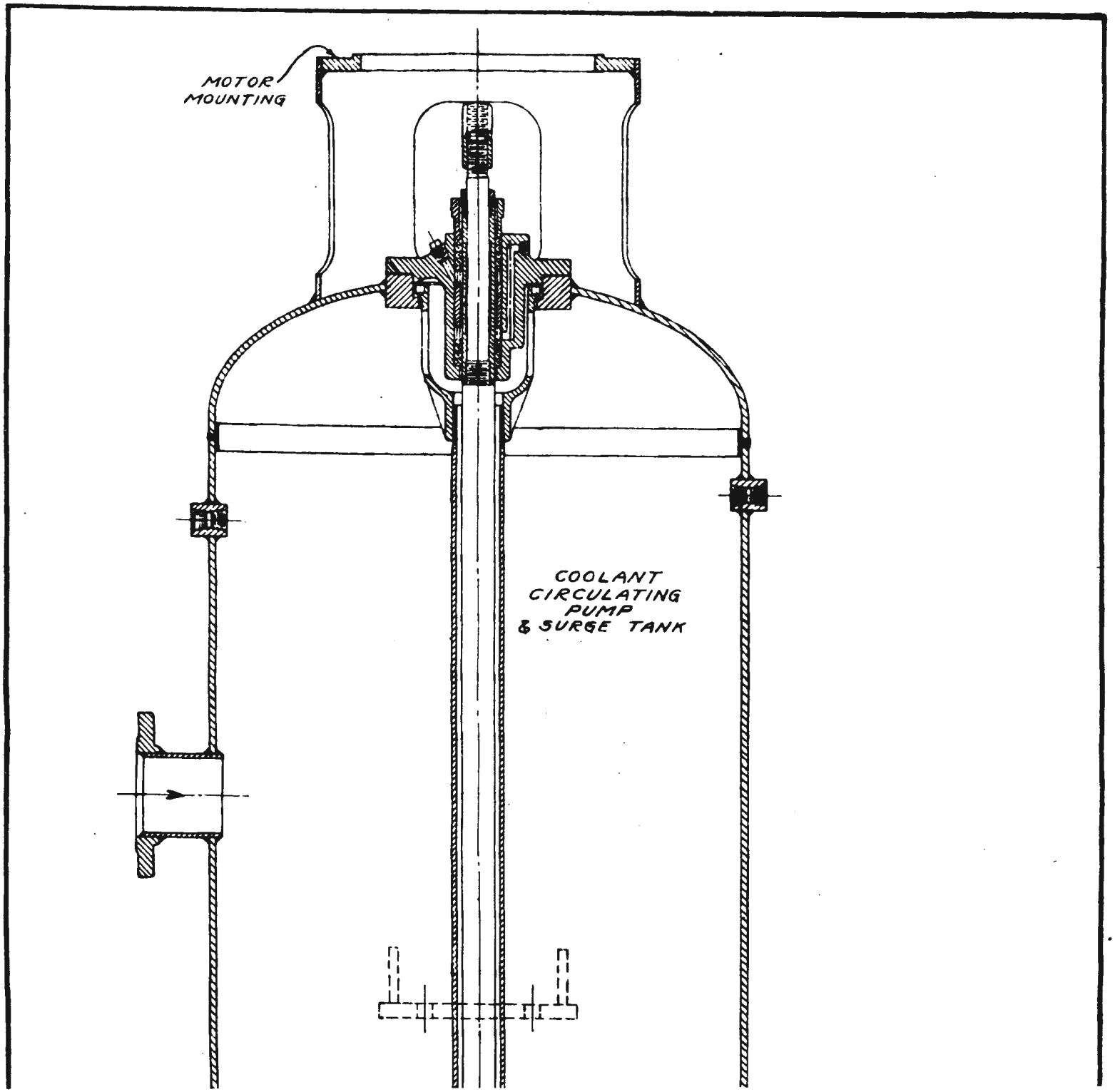
MOTOR
MOUNTING
COOLANT
CIRCULATING
PUMP
& SURGE TANK

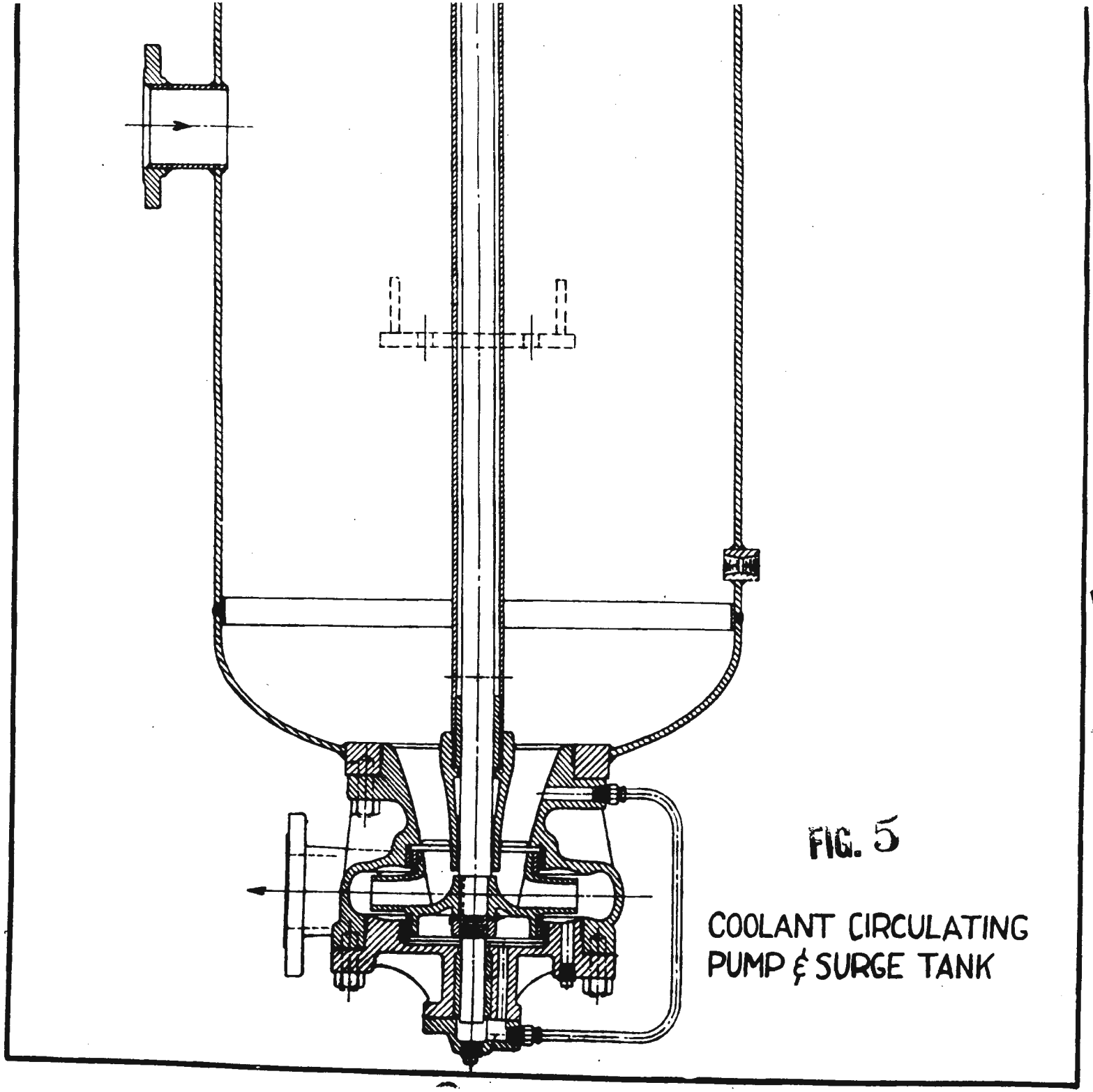

FIG. 5

COOLANT CIRCULATING
PUMP & SURGE TANK

5-7. Coolant Pumps. - A pump is required to circulate the special process coolant, perfluorodimethylcyclohexane, through the cooling system of each six-stage cell throughout the process cascade. About 700 such pumps are installed in sizes varying from 5 to 560 GPM under heads of 22 to 175 feet. Horsepower varies from 2 to 150. Since the coolant is expensive, it is important to minimize inventory and losses by leakage. The pump developed (Fig. 5) is of the vertical type, is mounted at the bottom of a surge drum, and takes suction directly from the bottom head of the tank. Pump bearings are lubricated by the coolant. The shaft passes up through a tube running to the top of the tank. A seal is placed at the upper end to prevent outleakage of nitrogen maintained under pressure in the top of the tank. The motor is mounted on top of the tank. In this way no liquid can be lost through the seal except the small amount which might vaporize into the nitrogen. Wagner motors were used, and the pumps were manufactured by Pacific Pumps, Inc.

5-8. Process Gas Vacuum Pumps.

a. Requirements. - These pumps are for evacuating process gas from equipment prior to maintenance, etc. Therefore, the by now familiar specification of no outleakage and very little inleakage was necessary. Whereas an ordinary vacuum pump possesses a leakage rate of about 50,000 micron cubic feet per hour, a rate of 1400 micron cubic feet per hour was the maximum permissible for a process gas vacuum pump. Welded construction and a special seal were necessary. All organic materials were ruled out to prevent consumption of process gas.

b. Development. - Early in 1944, Kellex and the Beach-Russ Company started development of a special rotary, oil-sealed mechani-

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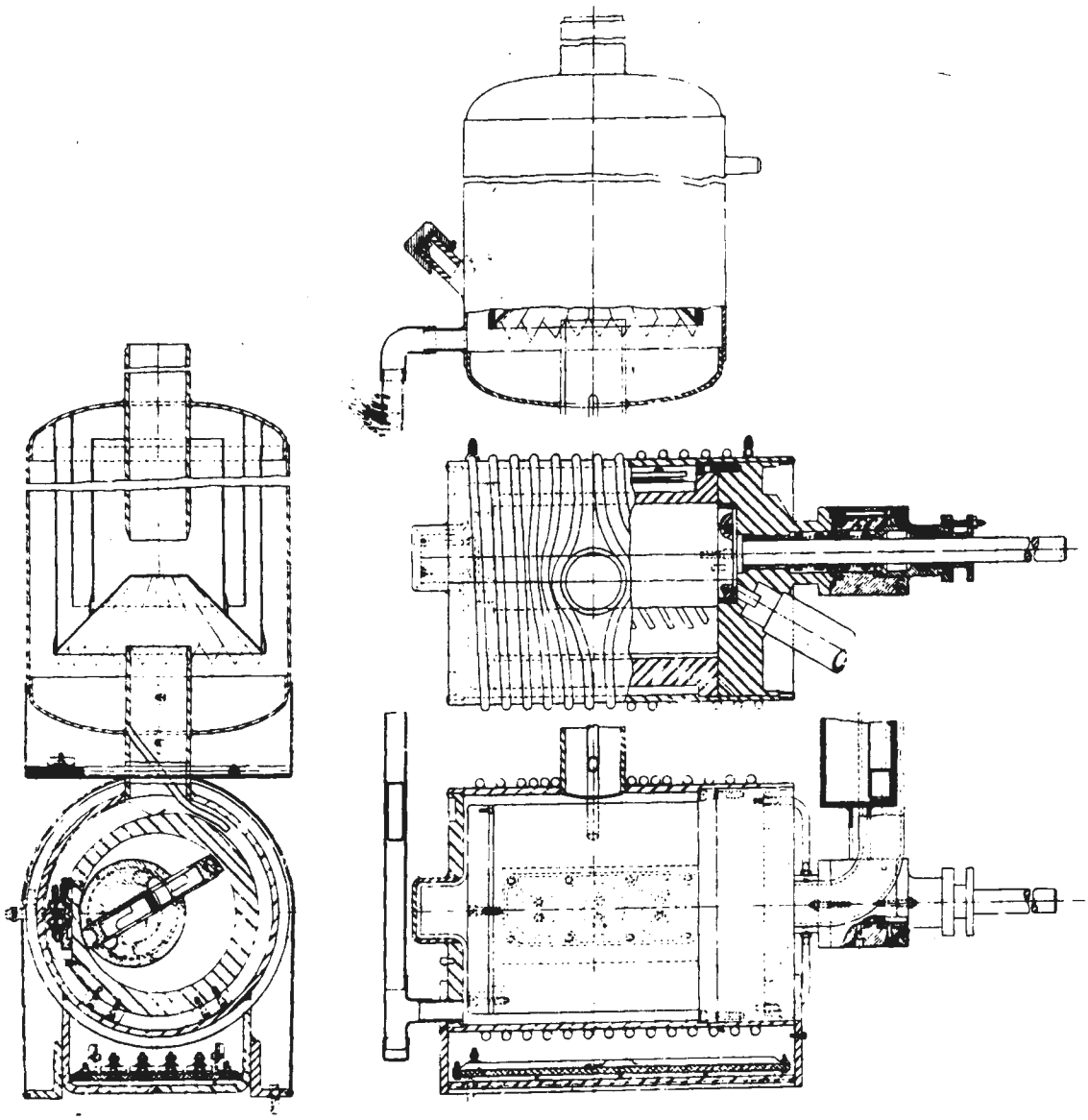

FIG. 6

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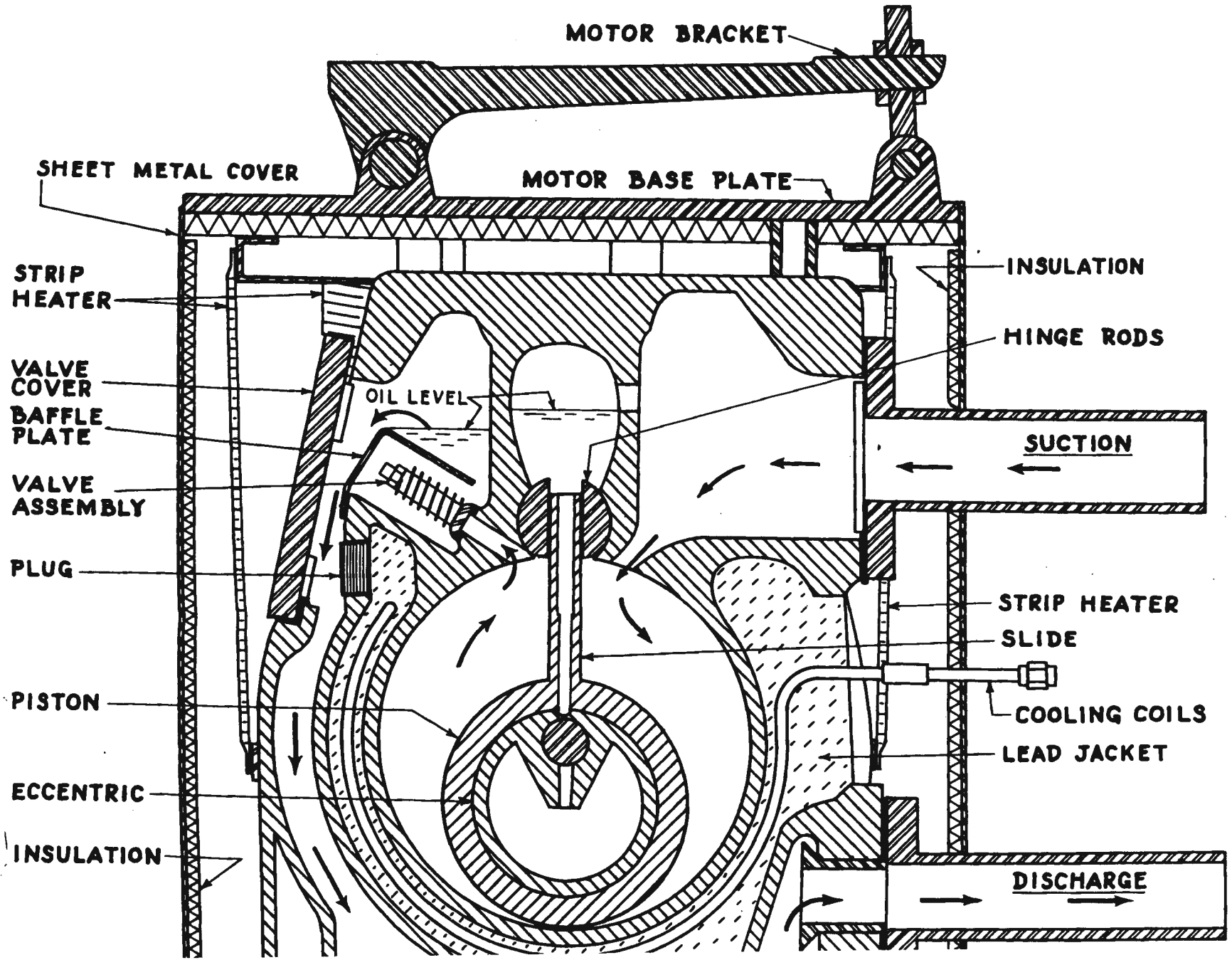
PROCESS GAS VACUUM PUMP

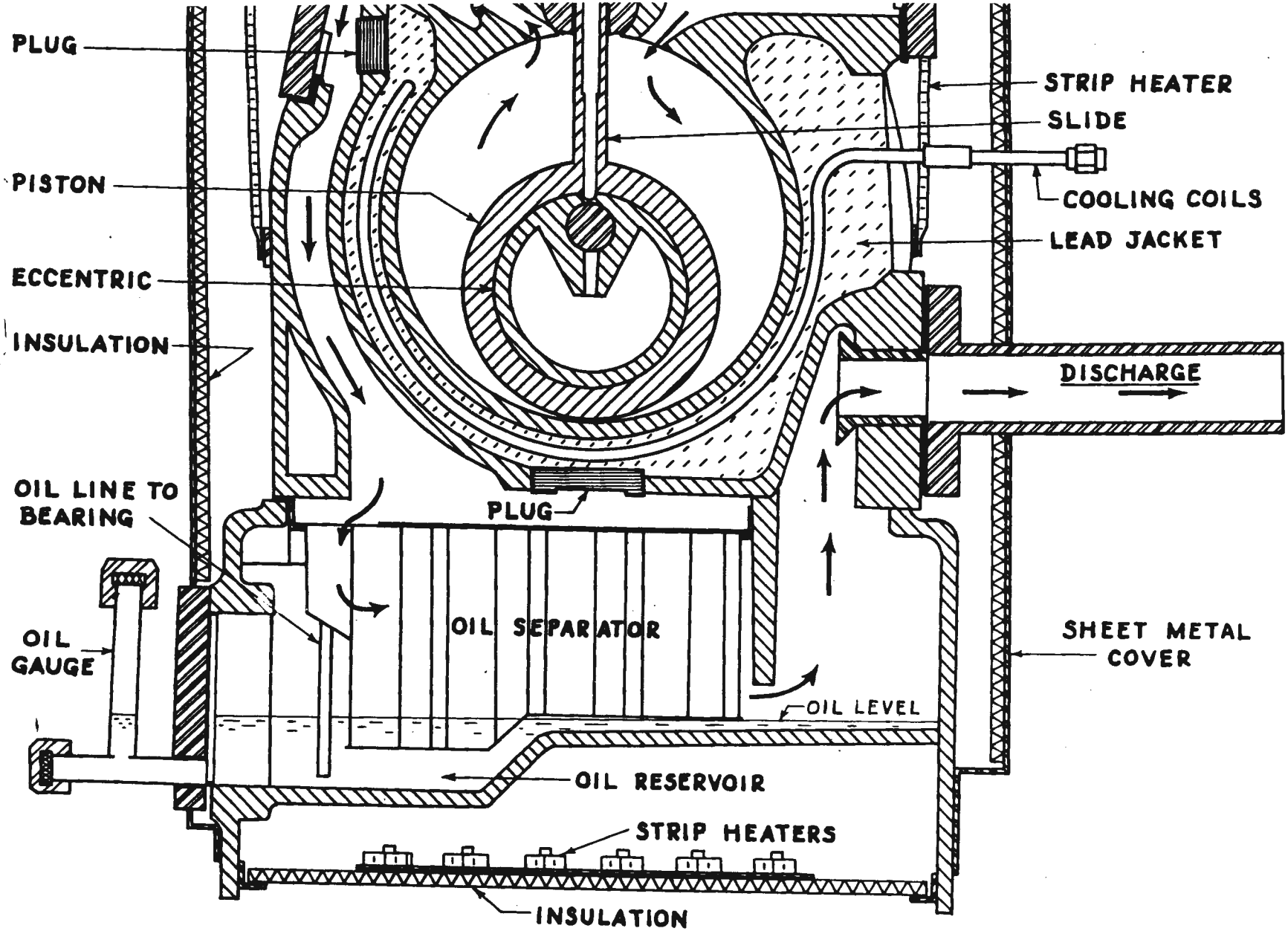
oal vacuum pump for process gas. A magnetic oil level indicator was developed to replace the conventional glass sight gauge. The usual cast iron was replaced by a material similar to SAE-65 bronze, and by low carbon steel. For easy access to the pump interior, welded vacuum joints were designed so that they could be machined or re-welded with relative simplicity. A quadruple shaft seal was provided, and special highly fluorinated inert seal oil was used. Electric heaters were installed to maintain an elevated temperature while the pumps were not running, for the purpose of reducing lubricant viscosity, as well as to prevent condensation of the process gas. However, at steady operating speed, heat generated is more than sufficient to maintain proper lubricant viscosity and keep the process gas in the vapor state. A cooling water system therefore had to be installed, and required a double metal separating wall to eliminate any possibility of water finding its way into the UF_6 stream. Copper tubing was wrapped around the shell of the pump and soldered to obtain good heat transfer. Figure 6 shows the final design.

5-9. Fluorine Vacuum Pumps. - These pumps are for evacuating conditioning gas from process equipment. Requirements are similar to those for the process gas vacuum pumps except that the outleakage specifications can be somewhat less severe. Work was undertaken early in 1944 by the F. J. Stokes Machine Company to develop a special, rotary, oil-sealed, mechanical vacuum pump to handle fluorine. Gasket and flange designs were completely revised to use aluminum and "British Formula Rubber". A rotary shaft seal was made up of materials resistant to fluorine. Castings were rigidly inspected to eliminate a possible

source of leakage due to porosity. As in the process gas vacuum pumps, a special seal oil was used, requiring an electric heating system. During operation, water cooling was required. This was provided by means of copper tubing in the cooling space. Molten lead was cast around the coils. The lead provided the necessary double wall, and acted as a heat transfer medium. With the oil used, which contained considerable hydrogen, fluorine consumption was high. This led to an increase of oil viscosity, blackening of the oil, and occasional burning of the pump valves. A series of tests was run in the Kellex Laboratories, circulating mixtures through the pumps of six and twenty per cent fluorine in nitrogen. On the basis of these tests, an operational procedure was outlined, controlling the fluorine concentration fed to the pump, and the upper limit was set at ten per cent. This did not impose severe restrictions on the conditioning operations which involved the use of these pumps. The final design is shown in Figure 7.

5-10. High Vacuum Pumps. - These pumps are used in connection with mass spectrometer leak detection work (Par. 6-4) to pump equipment to high vacuum. They handle air, require no special materials, and present no special problems. However, they must meet specific requirements of high speed, high capacity, and very high vacuum (10^{-3} to 10^{-7} mm. of mercury). It is also required that some of these units be rugged but portable. In the system chosen (Fig. 8), the equipment to be evacuated is connected to a "Primary Pump" (Fig. 8) which discharges to the "Booster Pump" (Fig. 10). These are both oil diffusion vacuum pumps. The gas then flows into a mechanical vacuum pump which is a Beach-Russ rotary piston, single stage, high vacuum, oil sealed unit. In order to


MOTOR BRACKET
SHEET METAL COVER
MOTOR BASE PLATE
STRIP HEATER
INSULATION
HINGE RODS
VALVE COVER
OIL LEVEL
BAFFLE PLATE
SUCTION
VALVE ASSEMBLY
PLUG
STRIP HEATER
SLIDE
PISTON
COOLING COILS
LEAD JACKET
ECCENTRIC
INSULATION
DISCHARGE



FLORINE VACUUM PUMP

Fig. 7

STOKES
VACUUM PUMP

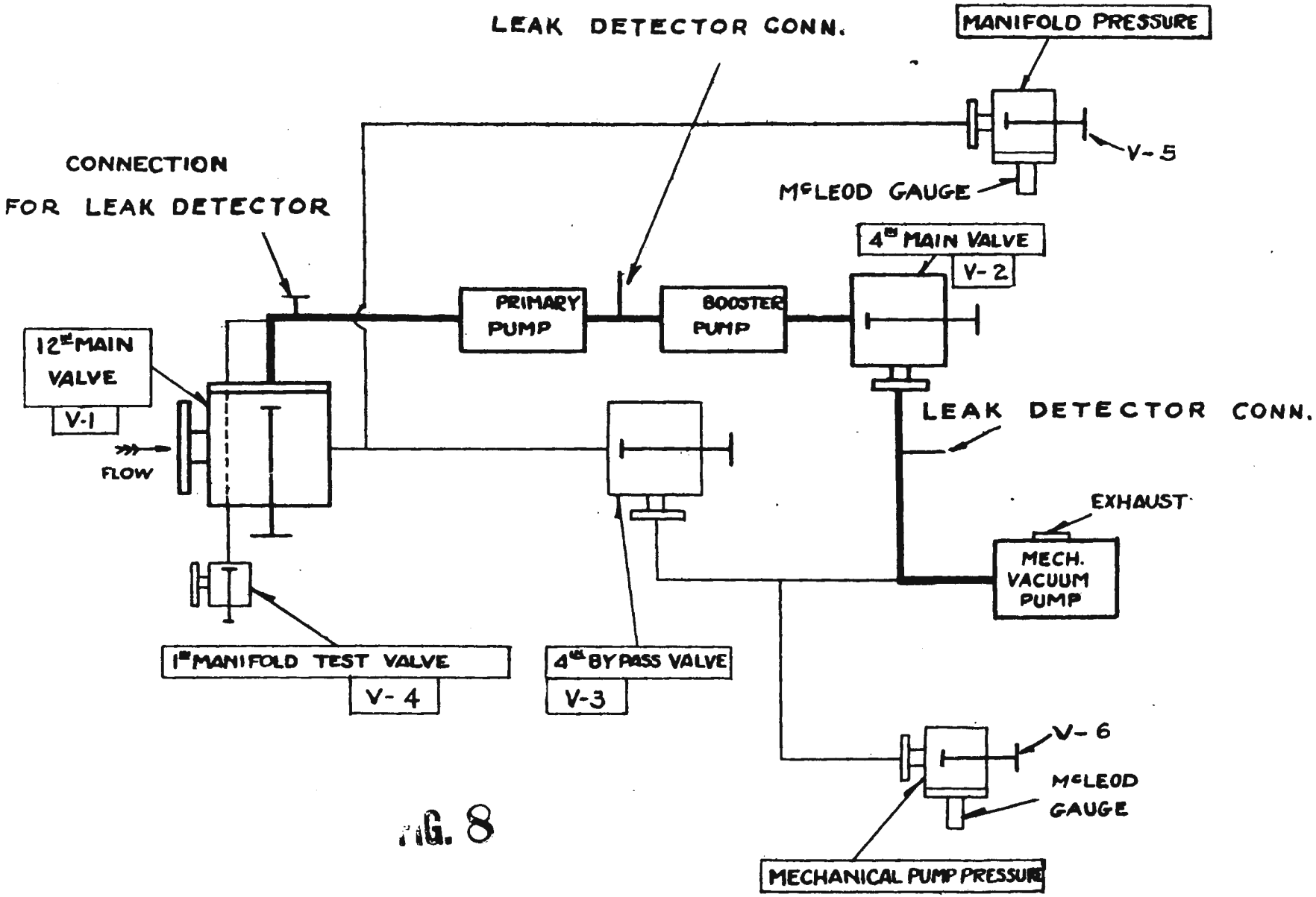


FIG. 8

VACUUM SCHEMATIC
2000 CFM PORTABLE UNIT

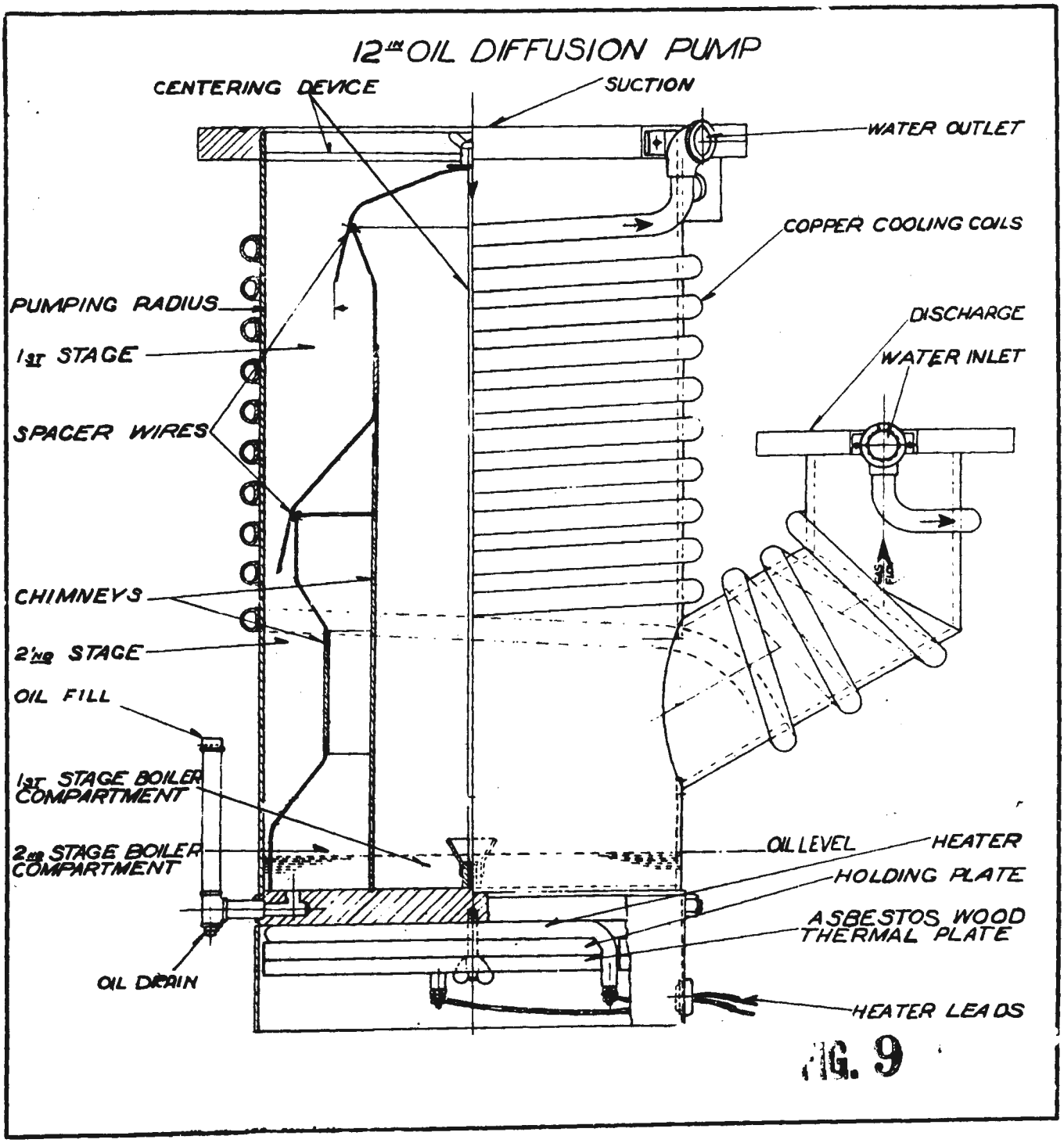

12" OIL DIFFUSION PUMP
CENTERING DEVICE
SUCTION
WATER OUTLET
COPPER COOLING COILS
PUMPING RADIUS
1ST STAGE
SPACER WIRES
DISCHARGE
WATER INLET
CHIMNEYS
2ND STAGE
OIL FILL
1ST STAGE BOILER COMPARTMENT
2ND STAGE BOILER COMPARTMENT
OIL LEVEL
HEATER
HOLDING PLATE
ASBESTOS WOOD THERMAL PLATE
OIL DRAIN
HEATER LEADS

FIG. 9

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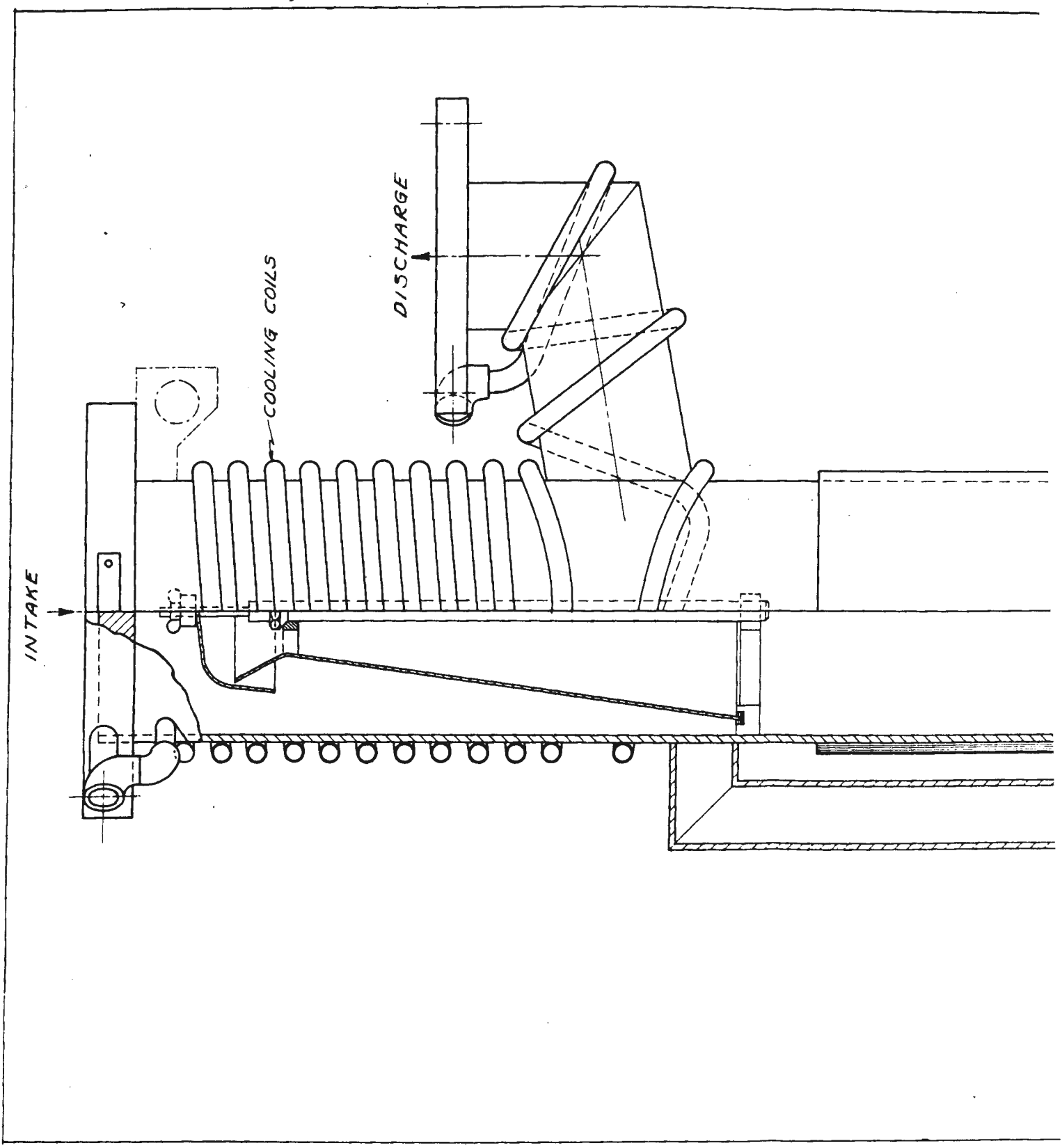
DISCHARGE
COOLING COILS
INTAKE

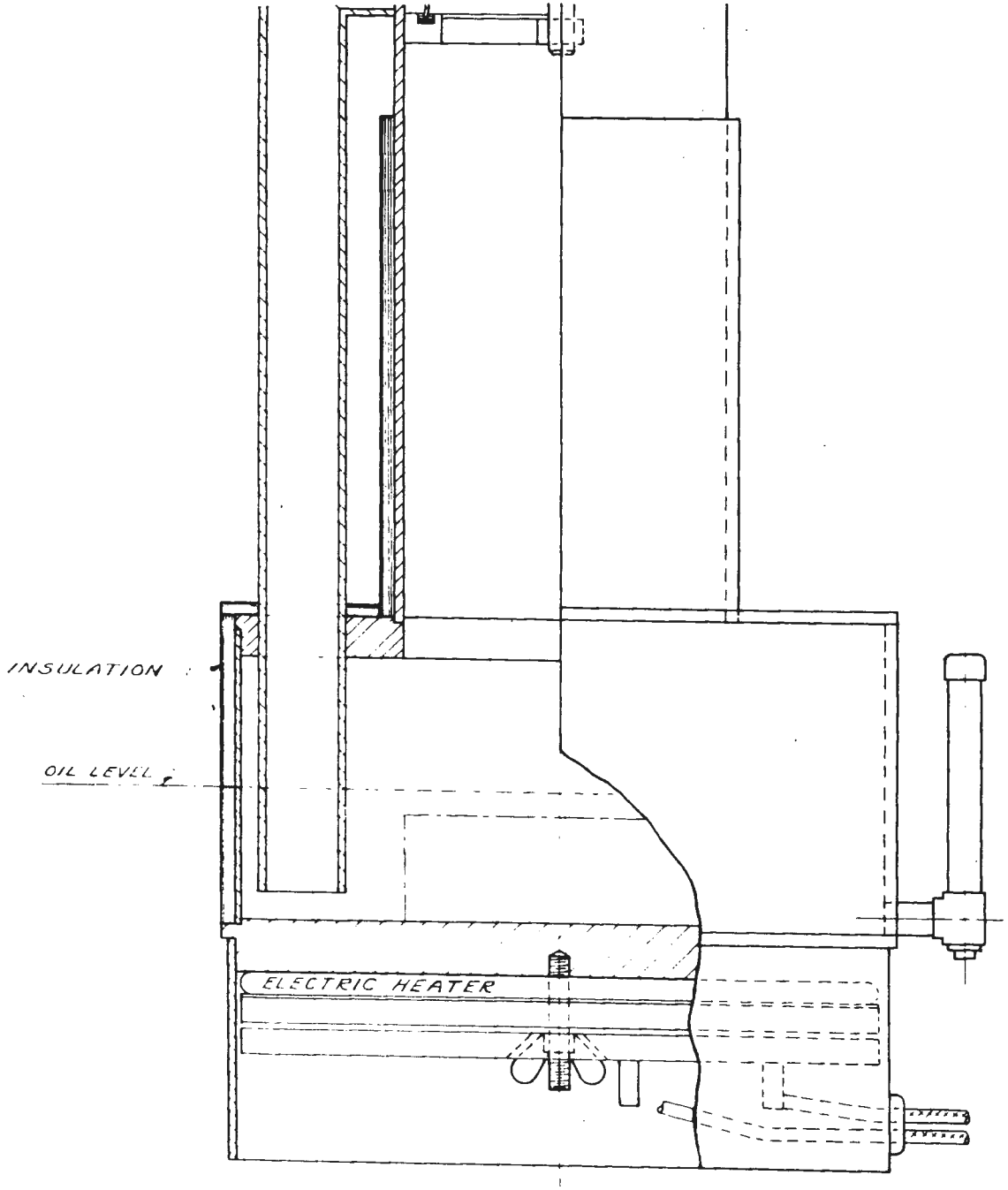

FIG. 10

BOOSTER OIL DIFFUSION PUMP

prevent oil vapor from diffusing or flowing back into the space being evacuated, a refrigerated vapor trap is installed ahead of the primary pump. This trap is cooled by a Westinghouse mechanical refrigerating unit. To develop the oil diffusion pumps, programs were initiated at National Research Corporation, the Westinghouse Electric and Manufacturing Corporation, Distillation Products, Inc., and the Kellex Nash Laboratories. The oil is heated electrically. Oil vapor rises in an inner chamber, and is directed downward, discharging through two annular nozzles into the space between the inner chamber and the shell. Copper cooling water tubing is wound around the shell and discharge connection to condense the oil vapor which then runs back down into the oil reservoir. A fluid leg between the inner chamber and shell walls prevents a back flow of vapor. For use throughout the process and conditioning areas at K-25, a total of about 185 units were finally ordered from Westinghouse in 2000 and 4000 cubic foot per minute sizes. Six units were bought from National Research for use at the Kellex Jersey City Test Floor (Vol. 3) and in the laboratories. Five units were purchased from Distillation Products for use in testing valves being manufactured at the plant of the Crane Company (Vol. 3).

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SECTION G - DEVELOPMENT OF SPECIAL INSTRUMENTS

G-1. General. - The usefulness and practicality of a production plant are completely dependent upon the proportion of positive control to which it is subject. Regulation of process variables, constant knowledge of process stream purity, and control of desired physical or chemical transformation taking place during the course of the movement of material through a step-wise series of processing operations are prime requirements for effective plant operation. Instrumentation is generally provided first for the purpose of determining operating variables and physico-chemical properties of the process stream, and second for the purpose of controlling these variables either manually or automatically. Superimposed upon the usual problems inherent in the planning, development, and operation of a workable system of instrumentation, there is presented at the K-25 plant a number of unusual requirements and conditions which necessitated a vast program of research and development including theoretical considerations, formulation of requirements, adaptation of available devices, and origination of new types to fit special needs. Among the special conditions obtaining within the K-25 plant may be listed the following:

1. Extensive need for determination of process stream purity at a great many points. It was deemed necessary to provide a means for continuous automatic determination of the individual proportions of process diluents such as nitrogen, oxygen, and coolant, at least at one point in every building of the main cascade, the K-27 cascade,

[redacted]

and the purge cascade.

2. Sub-atmospheric pressure of the operating process. This results in the danger, present throughout the plant, of inleakage of atmospheric air, an occurrence which cannot be tolerated.

3. Highly corrosive nature of the process material. Uranium hexafluoride reacts with glass, most metals, moisture, and organic materials.

4. Necessity for isotopic assay testing. Instruments capable of distinguishing between isotopes of a particular element are very few in number, and to date have had very infrequent application to industrial problems of plant control.

5. Nature of the mile-long gaseous diffusion process, which is ultra-sensitive to pressure waves and temperature variations. A continuous diffusional separation process demands a steady state. Pressure fluctuations, pumping disturbances, and similar variations set up waves and surges which cause mixing of streams and loss of separative production efficiency.

6. Severe consequences of variation of operating conditions from predetermined values. An inleakage of air or coolant at any one stage, for example, produces stream contamination at that point, which begins immediately to be carried in both directions, tending to spread throughout the whole cascade. This can result in reduced

production capacity and serious damage to the delicate and valuable barrier surfaces.

The vast scope of the instrumentation phase of the K-25 development program, and the exceptional technical complexity of the subject matter, preclude the presentation of more than a summary description in the present volume of the final method of application of the various principles utilized. Accordingly, the remainder of this section attempts, for the twelve outstanding developments in gaseous diffusion plant instrumentation, to describe the principle of operation in each case, the equipment design and arrangement finally chosen to take advantage of this principle, and the ultimate method evolved for operating the assembled unit. The majority of the devices described below were developed and manufactured by collaboration of the Kellex Corporation with the General Electric Company (App. D76, D77, D78). Considerable work was also done at the SAM Laboratories. Other firms participating in the program were the Moore Products Company (App. D75), the Taylor Instrument Company (App. D79), and the Republic Flow Meter Company (App. D80). The work done by these last-named concerns falls most properly under the heading of equipment design and procurement; discussion of this work is accordingly reserved for Volume 5. For more detailed treatment of particular aspects of the work on instrumentation, reference should be made to the Kellex Completion Report, Section III (10), to the pertinent operating manuals prepared by the Kellex Corporation (these are tabulated in Appendix C3 of Volume 6), and to training manuals of the Carbide and Carbon Chemicals Corporation.

6-f. Mass Spectrometer. - The mass spectrometer forms the basis

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of a number of the more numerous and more important instruments especially developed and engineered to fit the particular and exacting demands of the Gaseous Diffusion Project. The Kellex Corporation and the General Electric Company worked out the design and manufacturing procedures for this equipment. The mass spectrometer, or its forerunners, have been known for about thirty years. The instrument has provided a powerful tool for workers in atomic physics, and has recently been applied to analytical problems in several fields such as the petroleum and synthetic rubber industries. Unquestionably, its greatest application to date has been to assay and production problems within K-25 and other projects of the Manhattan District. Taking account of the differences in relative mass among the various individual molecular or atomic particles present in a gaseous mixture, the mass spectrometer is suited to isotopic as well as chemical assay testing, since, by definition, it is this atomic mass which distinguishes the several isotopes of a given element from one another.

a. Historical Survey. - The origin of the mass spectrometer dates from the year 1886, when E. Goldstein first observed what were called "canal rays" (App. D96). These were later found to consist of streams of ionized particles, and are now known as positive ion rays. In 1898 W. Wien first succeeded in producing deflection of ion rays by means of electric and magnetic fields (App. D99). Early work on dispersion of positive ion beams was done in 1907 by J. J. Thomson (App. D100). Later work by Thomson in 1913, involving studies of the behavior of light gases, enabled F. W. Aston to announce the important discovery of two separate isotopes of neon. In 1918 A. J. Dempster (App. D101),

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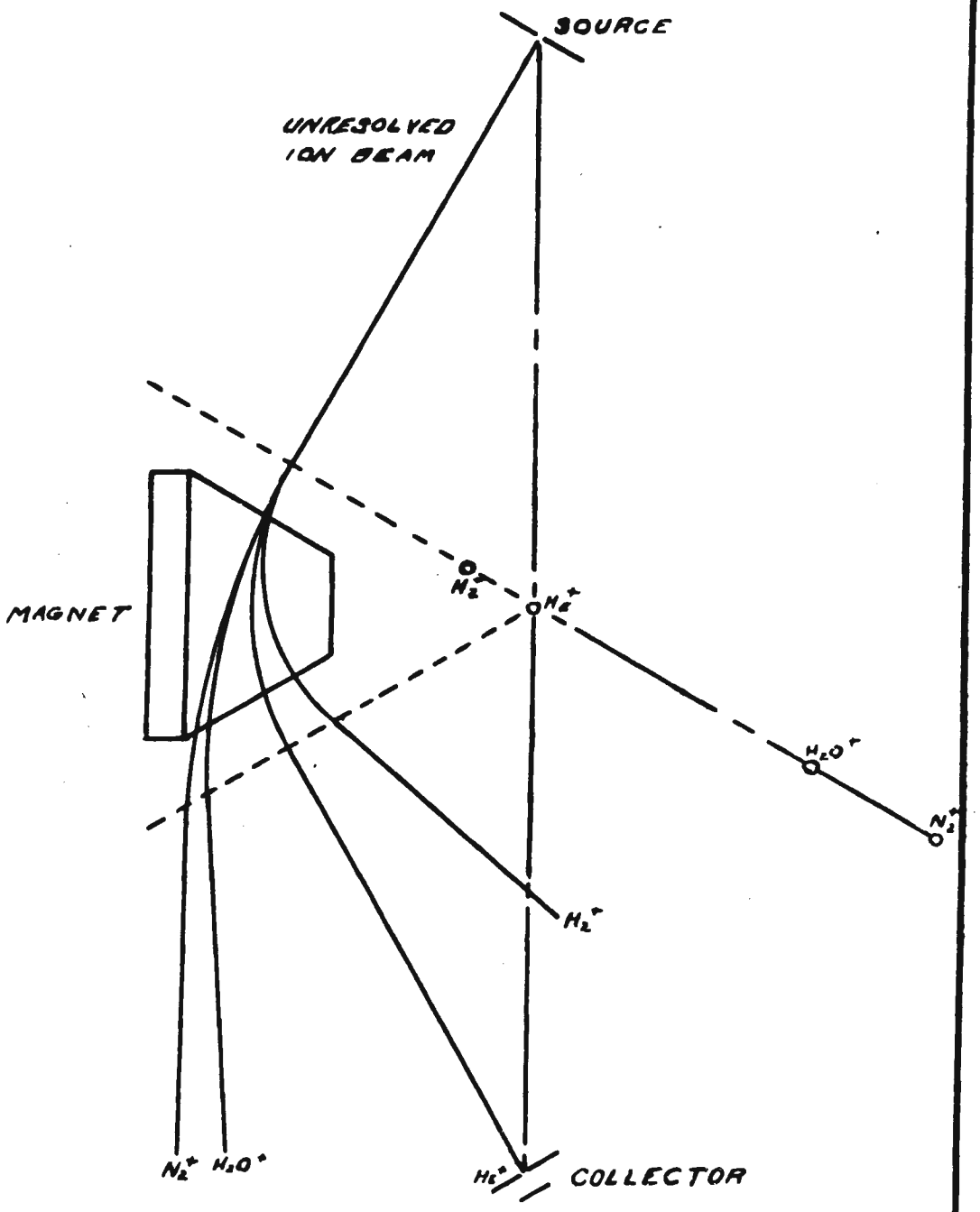
developed a direction-focusing technique for positive ray analysis, and in 1919 F. W. Aston (App. D102) devised a velocity focusing method. In 1933 Aston published a comprehensive text on the subject of mass spectrography, and described an instrument of advanced design (App. D103). Within the Manhattan District, the mass spectrometer received vigorous and intensive study and development chiefly under the direction of Dr. A. O. C. Nier (App. C29) working first at the University of Minnesota, and later for the Kellex Corporation. For an extensive historical treatment of the invention, development, and application of the mass spectrometer, as well as the story of its use on a gigantic production scale at the Y-12 Project, the reader is referred to Book V.

b. Principle of Operation. - Several fundamental principles are combined to form the basis for the operation of the mass spectrometer.

(1) Formation of Electron Beams. - A beam of high velocity electrons may be formed by enclosing within an evacuated space a hot filament and, at some distance from it, a positively charged plate. The hot filament will emit electrons, which will be attracted to the plate. The beam can be accurately aligned by impressing a magnetic field in such a way that its lines of force are parallel to the path of the electron rays.

(2) Ionization of Gases. - A rapidly travelling electron striking a gaseous molecule possesses the ability to dislodge one or more electrons from the gas molecule, causing it to become a positively charged ion.

(3) Acceleration of Gaseous Ions. - Positive gaseous



TITLE DISPERSION OF ION BEAM BY WEDGE SPECTROMETER

FIG. 11

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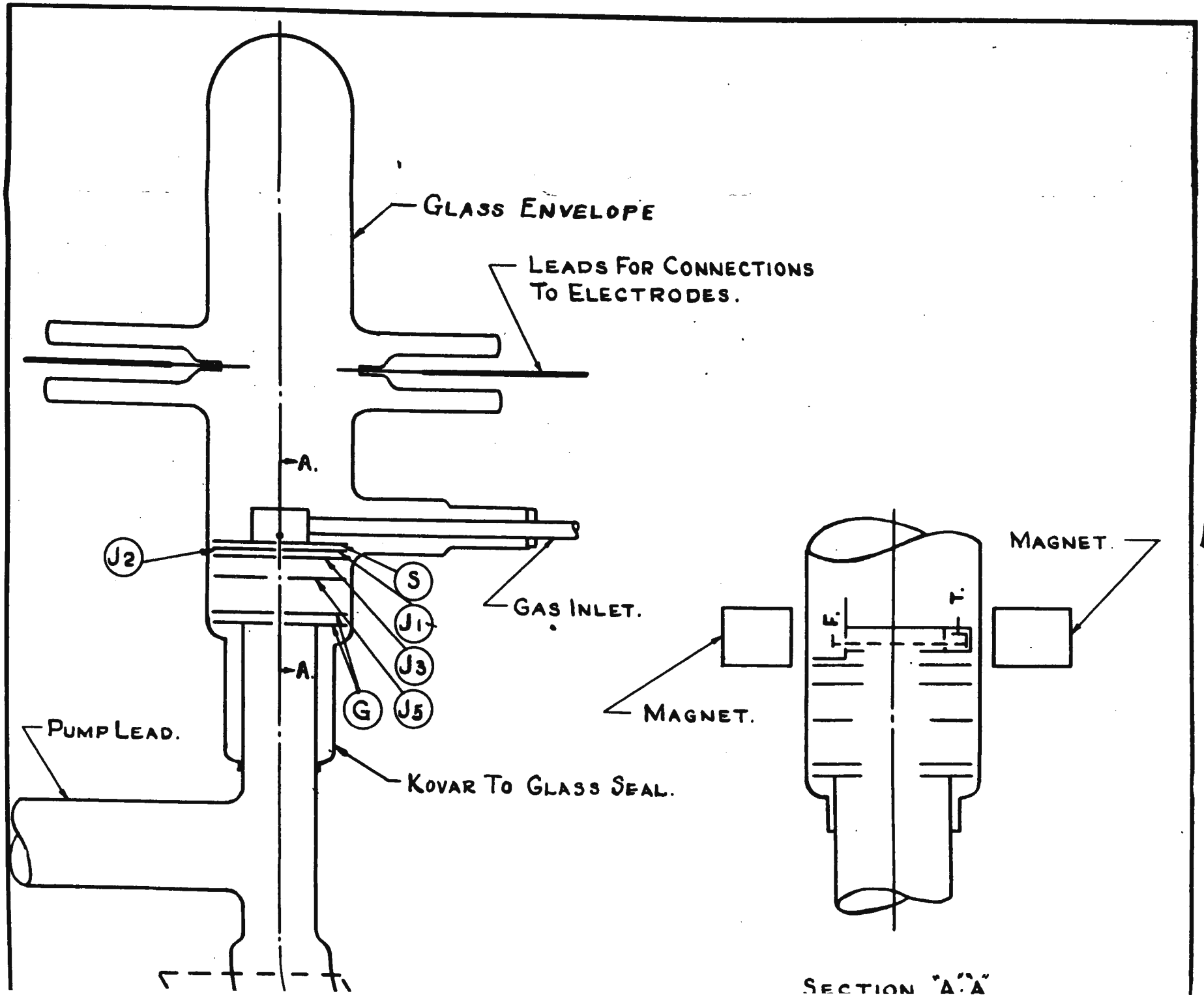
ions can be accelerated and directed toward a low potential target by subjecting them to the influence of a high strength electric field.

(4) Bending of Ion Rays. - Normally, the accelerated ions travel toward the target along a rectilinear path parallel to the lines of force of the electric field imposed. However, if a magnetic field is superimposed with its lines of force oriented in a direction perpendicular to the natural path of the ions, it will tend to deflect them from their straight line path, and cause them to travel in circular arcs, the amount of deflection being greatest for those ions of lowest mass (Fig. 11). That is, the heavier ions will travel along arcs of greater radius of curvature. If the ions were permitted to strike a target wall interposed approximately perpendicular to the direction of travel, it can be seen that the points at which ions of different masses strike would be distinct from one another, and would be arranged in the order of their respective relative masses. A means is thus available for separating molecules of different weights, and for sorting isotopes.

(5) Discharge of Ions. - As the positive ions strike the relatively negative target plate, they take up electrons, becoming electrically neutral. This results in the attraction of more electrons to the plate from the external circuit, i.e., flow of conventional electric current from the plate. The magnitude of the current produced will be in direct proportion to the number of ions discharged per unit time. If conditions are so arranged that only the ions of a specific mass are allowed to reach this "collector plate", measurement of the plate current will give an indication of the number of molecules of this particular mass.


GLASS ENVELOPE
LEADS FOR CONNECTIONS TO ELECTRODES.
A.
A.
J2
S
J1
J3
G
J5
GAS INLET.
PUMP LEAD.
KOVAR TO GLASS SEAL.
MAGNET.
MAGNET.
SECTION "A"-"A"

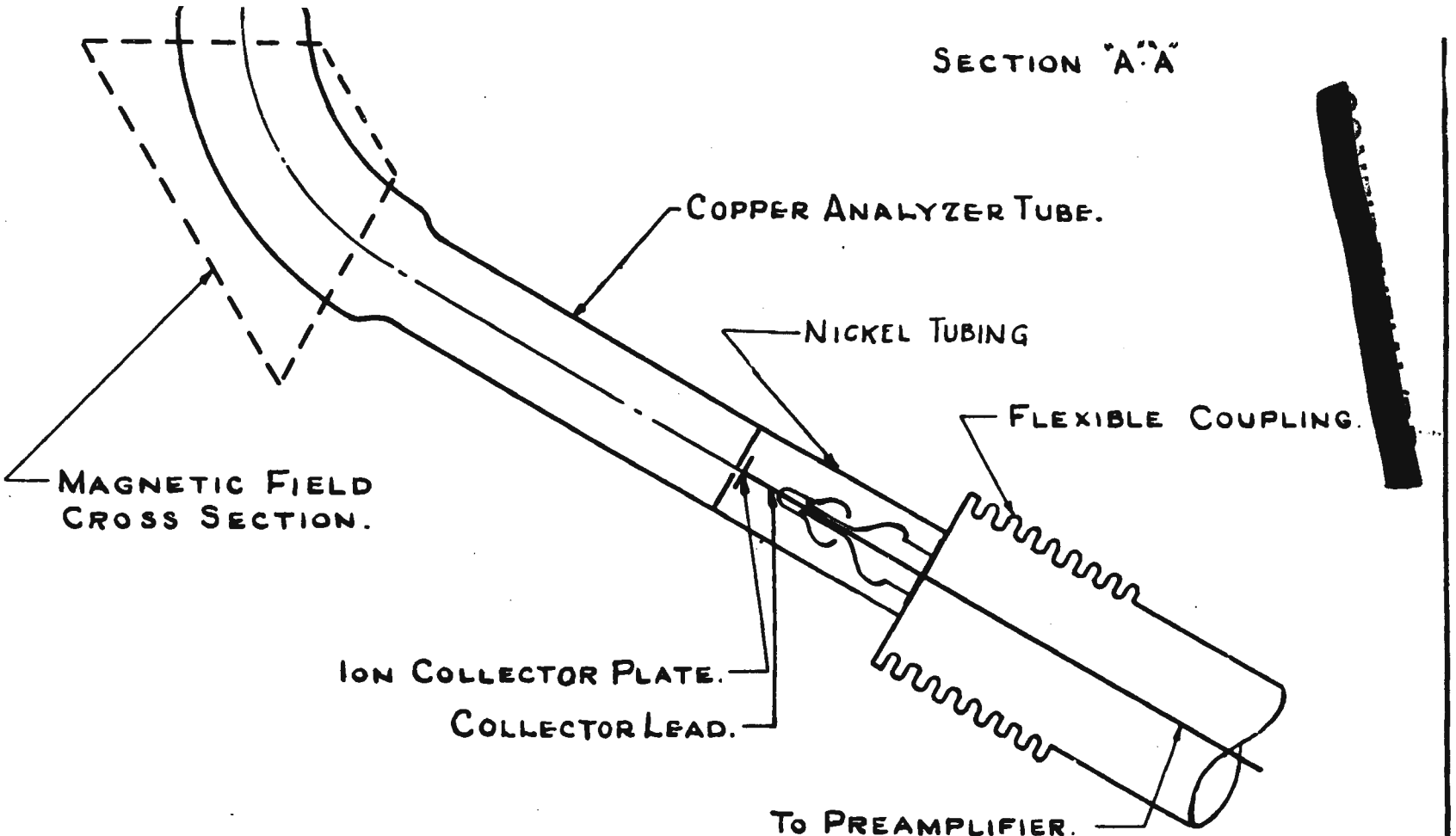


FIG. 12

SCHEMATIC DRAWING OF LINE RECORDER

TITLE SPECTROMETER TUBE.

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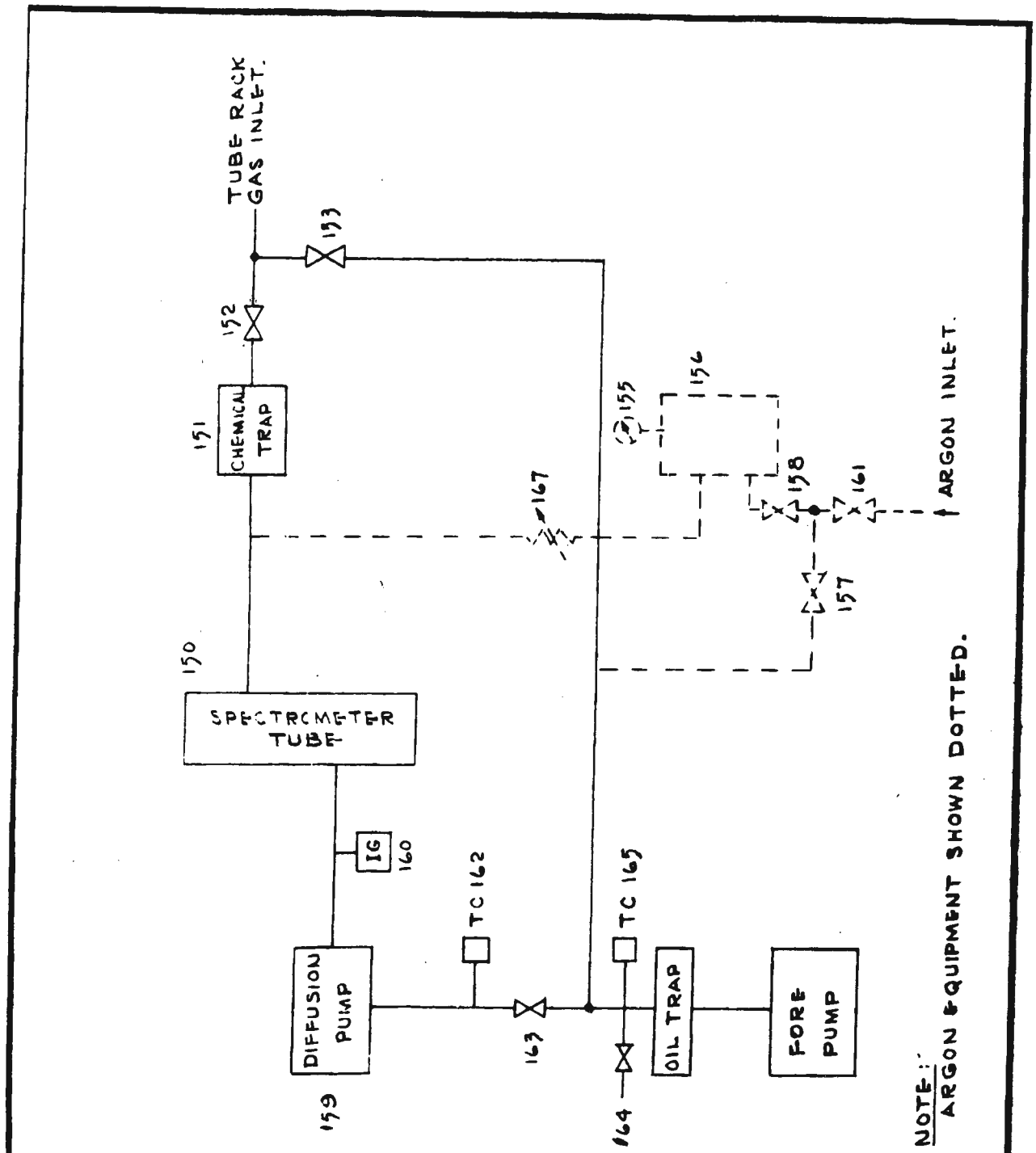
(6) Use of Slits. - This selective condition can be arranged by shielding out all ions except those of the desired weight. A shield can be inserted in front of the collector plate containing a narrow slit at the focal point of ions of the specific mass desired. They pass through the slit and strike the collector plate, while others are intercepted by the wall. Other slit arrangements can be employed in the apparatus to orient, focus, and aim the electron and ion beams. A striking analogy can be drawn between the aiming and focusing of ion beams by slits, and the similar control of light beams by glass lenses. The optical analogy is further strengthened, and visualization of mass spectrometer action aided, by comparing the dispersion of a mixed beam of ions of various masses to the dispersion of a beam of white light into its various component wavelengths by a triangular glass prism as applied in the well-known optical spectrometer. It is from this analogy that the name "mass spectrometer" is derived.

c. Component Parts. - Referring to Figure 12 which shows a typical spectrometer tube arrangement as used in the "Line Recorder" to be described below, the "source" and is housed in a glass envelope which is attached to the copper analyzer tube by means of a Kovar*-to-glass seal. The tubing surrounding the collector plate is made of nickel rather than copper to avoid the evaporation of metal on the insulation supporting the collector lead. A gas inlet and a 1-5/8 inch copper vacuum pump lead are provided. Sectional drawing "AA" shows the filament F and electron collector plate T. The poles of an Alnico* magnet are placed as shown for the purpose of accurately aligning the electron beam. In the main drawing, the electron beam cross section



FLOW SHEET FOR LINE RECORDER

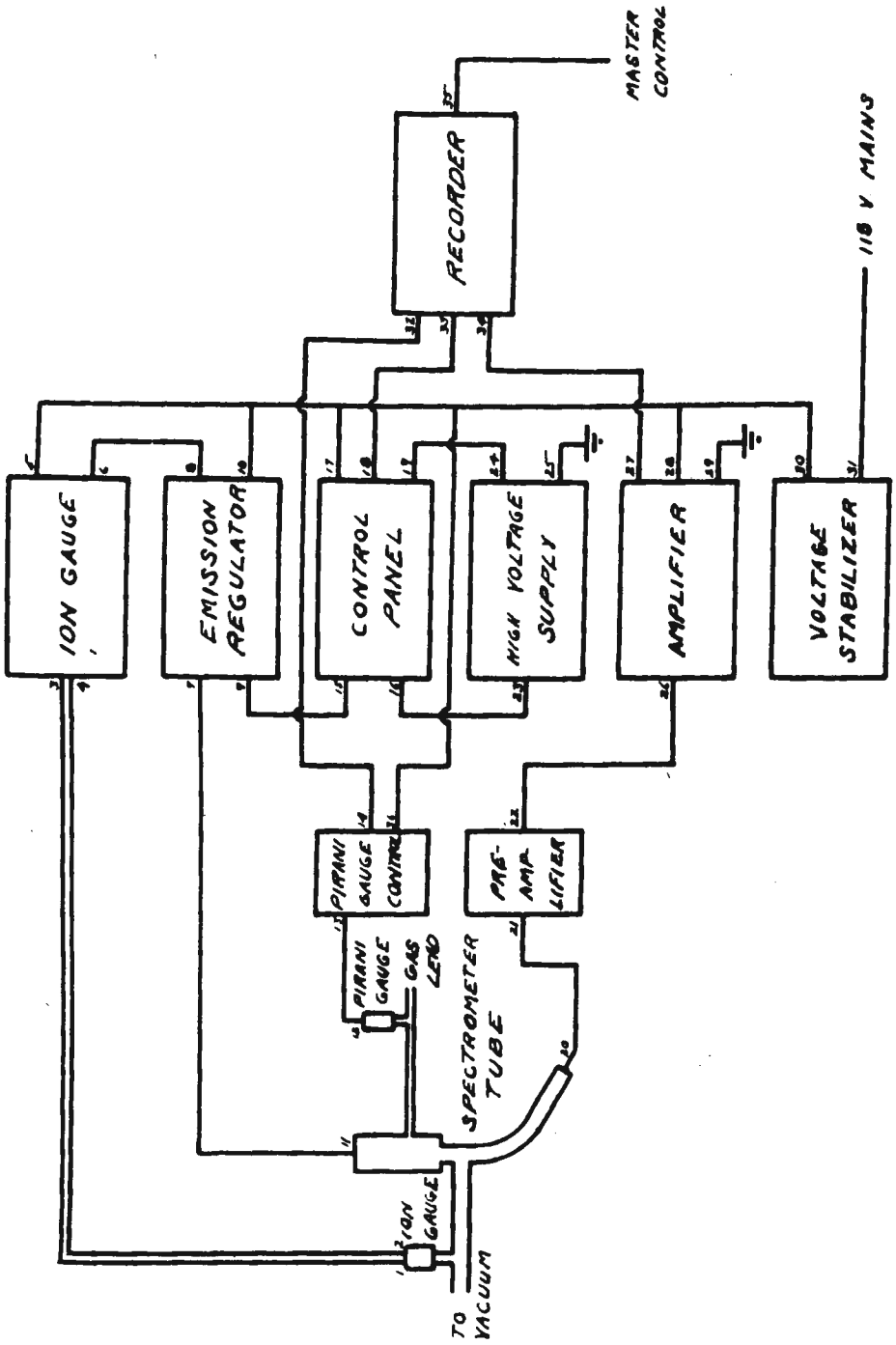
TITLE TUBE RACK.

FIG. 13

DESCRIPTION	DATE	CHECKED	THE KELLEX CORP.	SCALE ____ DATE ____ AP. ____ DR. ____ TR. ____ CKD. ____ No. ____ -D
REVISIONS				

is indicated as a heavy dot immediately above the slit in the shield S. A series of slit plates, J1, J2, J3, J5, and G are provided, in line with the source. J1 and J2 are a split pair, and permit bending of the beam to one side or the other to compensate for imperfections in alignment, as well as for the slight bending of the ion beam produced by the magnetic field used for aligning the electron beam. The remainder of the plates form a "lens" which not only increases the intensity of the ion beam entering the magnetic analyser, but also prevents a dropping off of ion intensity for all but the lowest energy ions. The two plates marked G are grounded along with the magnetic analyser housing to which they are tied.

d. Method of Use. - The spectrometer tube is continuously evacuated by means of a diffusion pump and mechanical fore pump system. Sample gas is introduced into the source box and ionized by the electron beam. An ion beam is formed and accelerated through the analyser tube. The relative amount of a particular constituent is determined by measuring the collector plate current with accelerating voltage difference between the positive electrode and the collector plate so adjusted as to cause this constituent only to focus on the slit in the collector plate shield. Selection of the component to be so measured is made by suitable regulation of accelerating voltage, since for a given magnetic field strength, the curvature of the path followed by each ionic species will increase as this voltage is lowered. An alternate method of ion selection could be worked out based upon the regulation of the magnetic field strength. However, the first method is employed in mass spectrometers at K-25. Specific applications for instruments utilizing the



TITLE ELECTRICAL CONNECTIONS BETWEEN COMPONENTS OF LINE RECORDER

FIG. 14

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mass spectrometer principle are presented in the next three paragraphs.

6-3. Line Recorder. - Effective operation of the K-25 plant requires that the chemical composition of the process stream be known at all times and at many points. This is necessary in order to determine process conditions and to detect various types of leaks as soon after formation as possible. Continuous analyses are run primarily to detect an abnormal rate of inleakage as soon as it occurs so that if it is serious, immediate corrective action may be taken. The line recorder thus serves primarily to keep a continuous graphic record of the concentration of various contaminating gases, but also presents a means of checking cascade inventories. It was developed by the instrument department of the Kellex Corporation with the cooperation of the General Electric Company, who manufactured the units installed in the plant.

a. Principle of Operation. - The heart of the line recorder is a mass spectrometer of moderate resolving power. A number of accessory parts and auxiliary instruments are required, and were especially adapted for this service. The special principles involved in the operation of these items are described below.

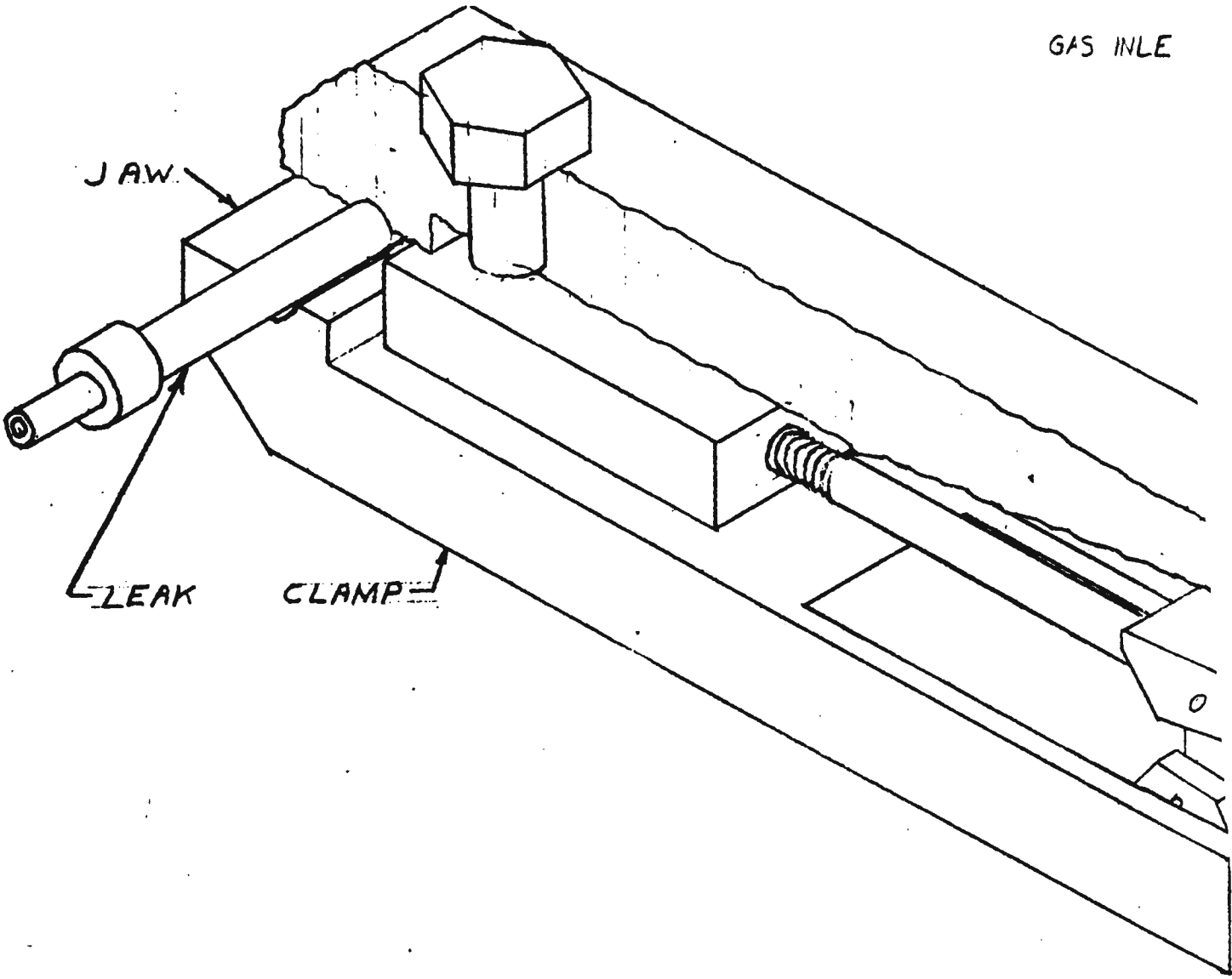
b. Component Parts. - The schematic flow diagram for the line recorder is depicted in Figure 13 (facing p. 6.8). The electrical connections are represented in Figure 14. Figure 18 (facing p. 6.13) shows an isometric drawing of the complete assembly.

(1) Mass Spectrometer. - The function and finally adapted fabrication details of the mass spectrometer tube, or line recorder proper, have been described in Paragraph 6-2, and are depicted schematically in Figure 12, facing page 6.7.

(2) Pirani Gage. - The Pirani gage is actually a pressure indicating instrument, but is used in the line recorder to measure rate of flow of the gas sample entering the spectrometer tube, since flow rate and pressure of the gas are interdependent. It is based upon the principle that, within the pressure range involved, the rate of heat loss, and hence the temperature, of a heated wire, depend upon the pressure of the surrounding gas. The temperature of the wire is measured by noting its change in electrical resistance.

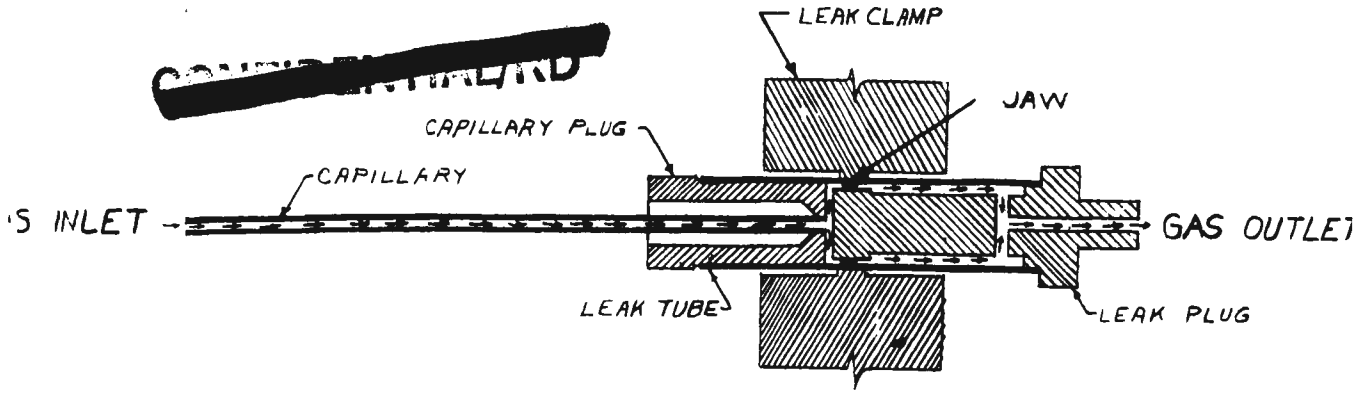
(3) Adjustable Leak. - It is necessary to control the gas flow at the inlet of the tube rack because the spectrometer tube is built to operate at a Pirani gage reading of about 100 millivolts. To regulate accurately the extremely small flow required, a novel valve was specially devised known as the "adjustable leak". As shown in Figure 16, the gas is throttled by passage through a small annular space the size of which is dependent upon the pressure on the leak tube, which is regulated by a clamp. A capillary tube is provided at the entrance to the leak in order to prevent effusive fractionation and change of composition of the gas passing through the leak. The adjustable leak could reduce an atmospheric supply pressure to 1.7 millimeters of mercury.

(4) Chemical Trap. - In order to prevent tube contamination by deposition of UF_6, a chemical trap is provided to remove, by reaction with mercury, the uranium hexafluoride from the gas mixture entering the tube rack before it enters the spectrometer tube. The trap is shown in Figure 16. Mercury distills from its reservoir and diffuses through the 1/2 inch holes in two nickel tubes which serve as



TITLE Adj

DESCRIPTION



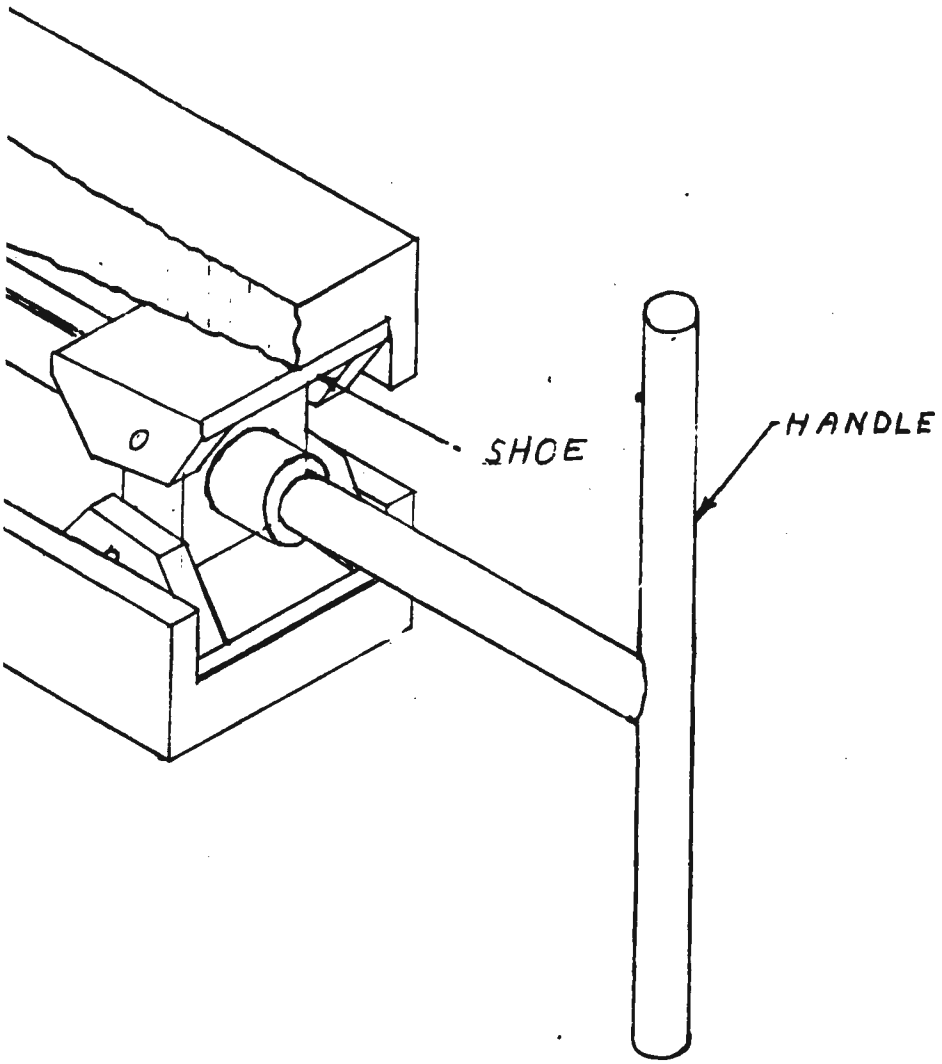


FIG. 15

ITLE Adjustable Leak Clamp

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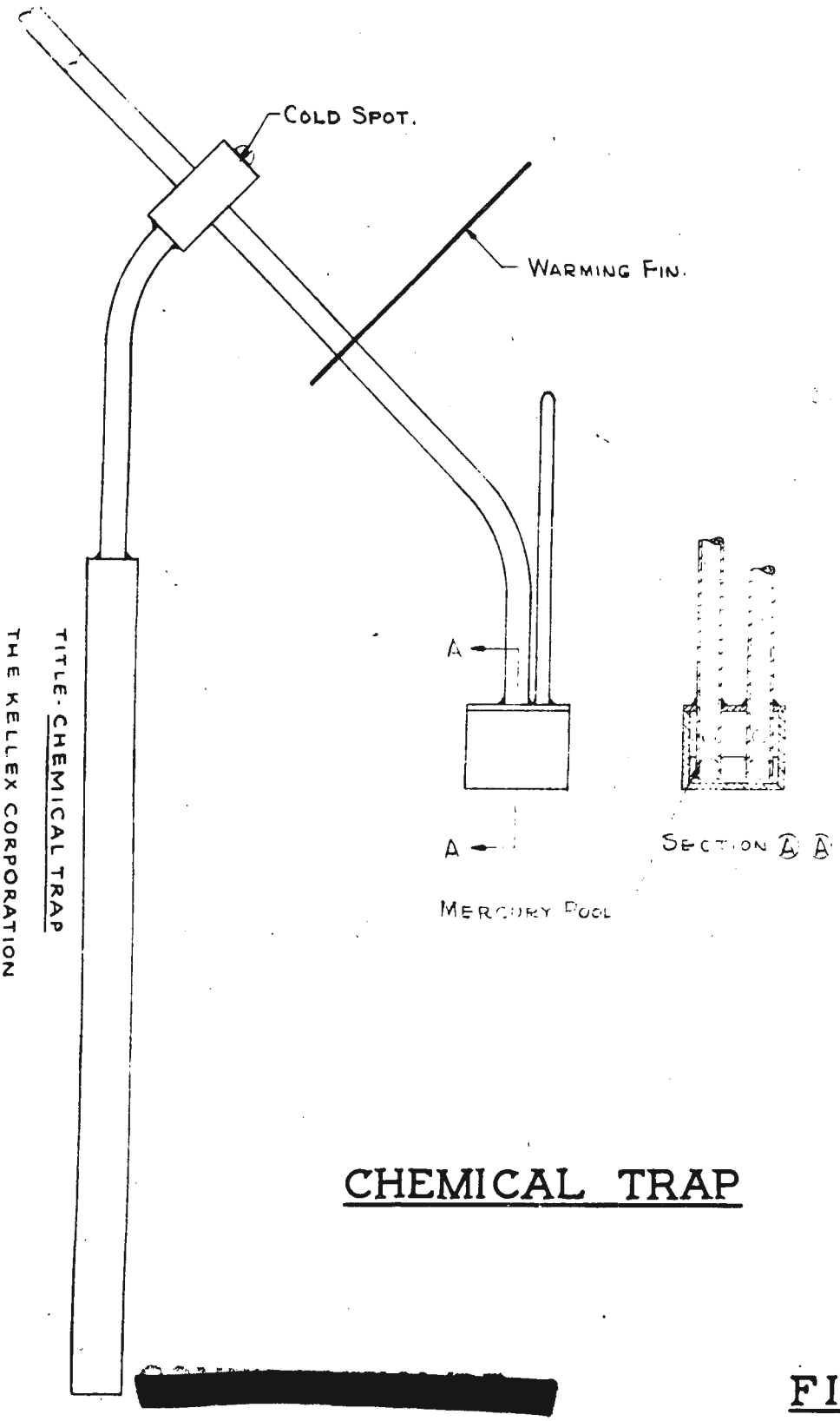

CHEMICAL TRAP

FIG. 16

entrance and exit lines, respectively, for the gas to be analysed. Upon reaching the cold spot, the mercury condenses in sufficient quantities to reduce its pressure at this point to its usual value at the cold spot temperature. The condensed mercury then continues on, and reacts completely with the UF_6 a short distance up the tube. Excessive quantities of distilled mercury may drop back into the reservoir, together with any reaction products which flake off the walls of the tube. To prevent these reaction products from "poisoning" the mercury surface, the nickel tubing is extended below the surface so that the region below the holes in the tubes acts as a trap. The cold spot confines the reaction region, and limits the mercury pressure. To make certain that the mercury does not condense before reaching the cold spot, a warming fin is attached. This also prevents any excessive cooling of the reservoir, and assures ample flow of mercury to the cold spot. The low temperature of the cold spot is maintained on each of the two nickel tubes by means of a copper finger submerged in a slush of trichlorethylene and dry ice. The closed tube shown in the figure, projecting vertically from the reservoir chamber, is the mercury charging line.

(5) Glass Trap. - Gases leaving the spectrometer tube pass through a glass trap immersed in liquid nitrogen. The function of this trap is to freeze out mercury vapor which might find its way into the stream from the mercury diffusion pump. The trap also prevents the vapor pressure from interfering with the ion gage reading, and eliminates the possibility of mercury vapor entering the spectrometer tube.

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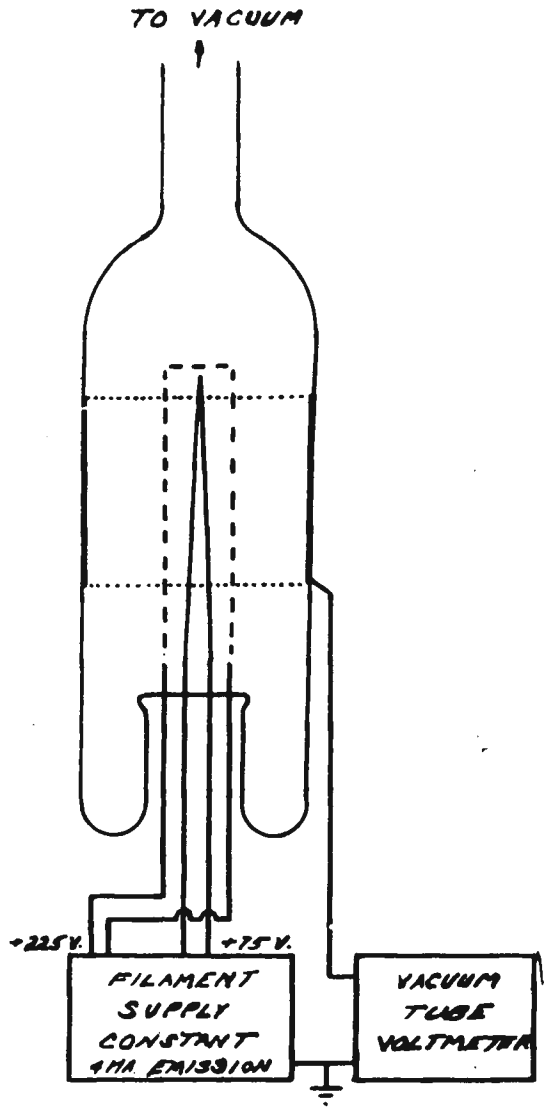

PLATE CURRENT OF VG-1A = 100 μA / MICRON PRESSURE

TITLE IONIZATION GAUGE

FIG. 17

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(6) Ionization Cage. - An ion gage tube (Fig. 17) was adapted and manufactured by Distillation Products, Inc. It is connected to the glass trap inlet to measure the spectrometer tube pressure at the pump lead. It is set to shut itself and the spectrometer tube filament off in case of vacuum failure, so as to avoid burning out of a filament. It consists of a source of electrons which fall through a potential drop of 100 or more volts, and a means of collecting the positive ions formed from the gas by electron bombardment. The ions formed are collected by the negative plate. The resultant plate current is measured; for a fixed electron emission, it is proportional to the gas pressure.

(7) Pumping Equipment. - A two stage mercury diffusion pump is provided, having a capacity of six liters per second at a pressure of 10^{-6} millimeters of mercury. It is backed by a mechanical fore pump, and an oil trap is inserted between the two pumps so that, in case of failure of the mechanical pump, its oil will not be drawn into the diffusion pump. Two thermocouple gages are provided to measure the fore vacuum. Similar to the Pirani gage, these are also "hot wire gages" and determine gas pressure from wire temperature, but instead of measuring the wire resistance, a thermocouple and millivoltmeter are used to indicate the temperature of the wire directly.

(8) High Voltage Supply. - 2500 volts direct current is required for the operation of the line recorder.

(9) Control Panel. - The function of the control panel is to divide up the high voltage so that the proper accelerating voltage appears at the source.

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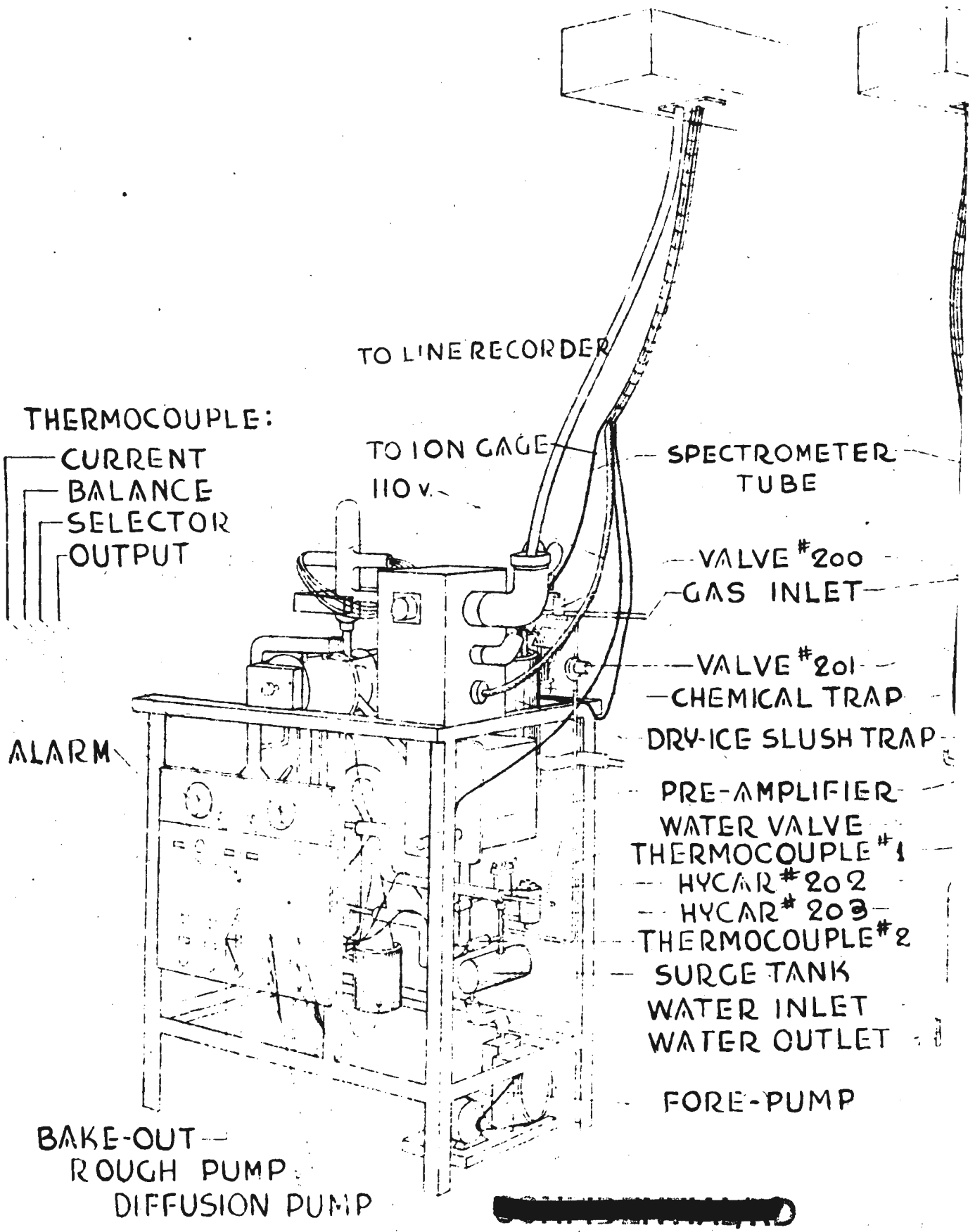
TO LINE RECORDER
THERMOCOUPLE:
CURRENT
BALANCE
SELECTOR
OUTPUT
TO ION GAGE
110 V.
SPECTROMETER TUBE
VALVE #200
GAS INLET
VALVE #201
CHEMICAL TRAP
DRY-ICE SLUSH TRAP
ALARM
PRE-AMPLIFIER
WATER VALVE
THERMOCOUPLE #1
HYCAR #202
HYCAR #203
THERMOCOUPLE #2
SURGE TANK
WATER INLET
WATER OUTLET
FORE-PUMP
BAKE-OUT
ROUGH PUMP
DIFFUSION PUMP

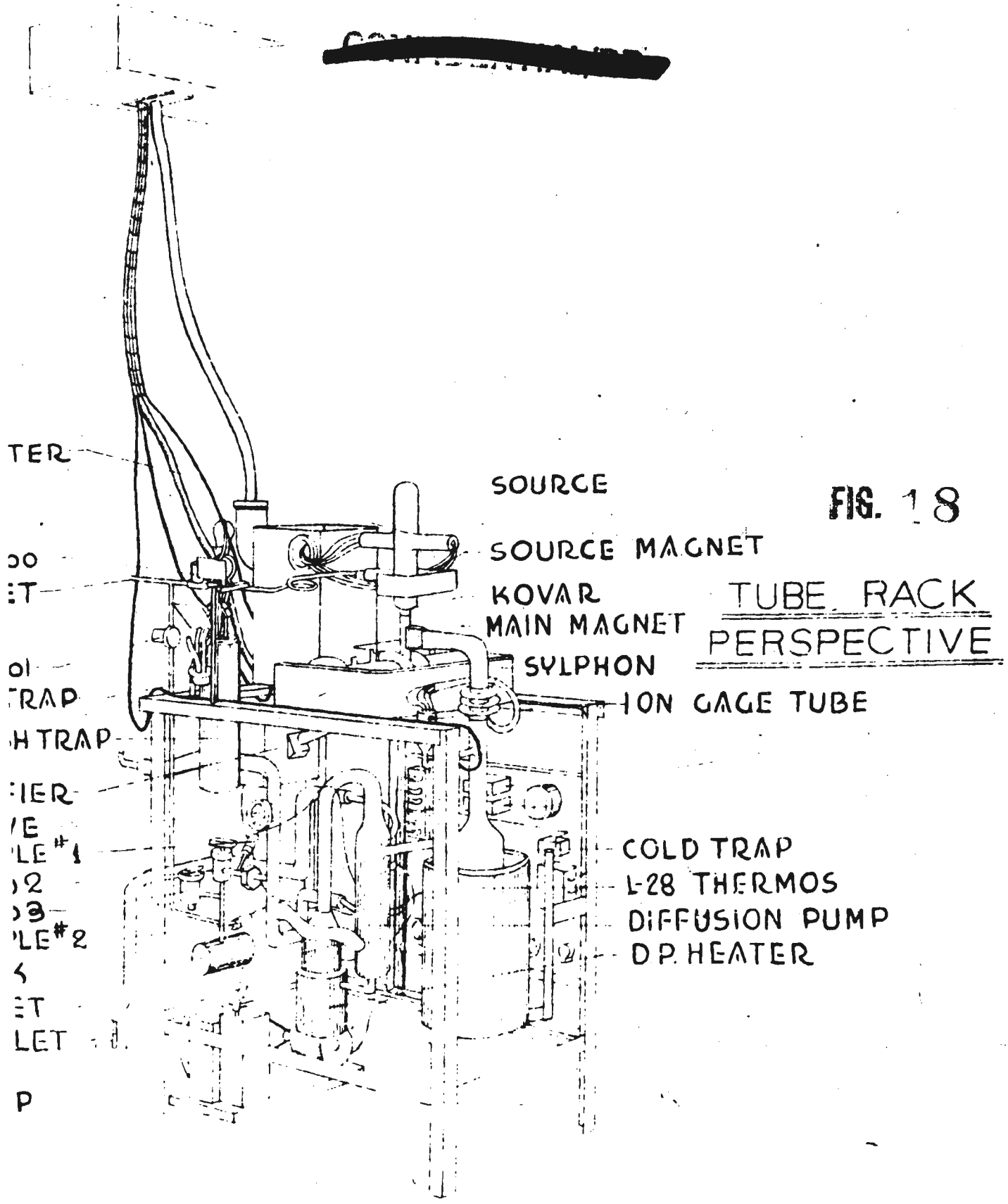

FIG. 18

TUBE RACK
PERSPECTIVE

(10) Emission Regulator. - An emission regulator is included in the design to furnish voltages for the remainder of the source, and to provide filament current so regulated that the total emission remains constant.

(11) Argon System. - Means were originally provided for introducing a small quantity of argon into the gas stream as a calibrating gas to show any changes in sensitivity caused by aging of the tube. This equipment is not used and is being removed from the line recorders. Standard UF_6-nitrogen samples are now used for calibration.

(12) Amplification System. - The pre-amplifier and amplifier serve the important function of measuring the ion current. Currents as low as 10^{-12} amperes can be brought within a measurable range by the use of this apparatus. The amplifier consists essentially of a vacuum tube voltmeter with a high resistance grid circuit.

(13) Voltage Stabilizer. - The voltage stabilizer is a commercial stabilizing unit which is intended to smooth out fluctuations in the 115 volt alternating current obtained from the mains; use of this device makes it possible to simplify the design of the other accessories.

(14) Recorder. - The recorder mechanism switches the spectrometer tube voltages to the required value for each ion to be measured, selects the sensitivity of the amplifier, and records the individual component concentrations in terms of amplified plate currents, by means of a Leeds and Northrup recording potentiometer. The various diluent concentrations are thus examined in a prearranged and continuously repeated sequence. The result is a set of curves which graphically portray the time-variation of each component.

c. Method of Use. - Part of the discharge from the A pump of the sixth stage of the cell being monitored is circulated continuously to the operating floor through a heated manifold and returned to the suction of the same pump. About three cubic centimeters (or 40 milligrams) per day of UF_6 is bled to the spectrometer tube by means of the adjustable leak. The tube operates at 10^{-5} - 10^{-7} millimeters of mercury. The total flow rate of gas entering the tube rack is measured by means of the Pirani gage. UF_6 is chemically removed from the stream before it reaches the spectrometer tube, and residual gases are measured by means of the spectrometer. Sixteen points are included on the printing device which operates on a 6.4 minute cycle. All even-numbered points record the concentration of nitrogen, which is ordinarily the most preponderant and most important diluent. Points 1 and 9 record oxygen concentration, and point 5 gives an indication of the presence of hydrogen fluoride. It is not possible to measure the latter component accurately since much of it is pre-absorbed by the chemical trap before the sample stream reaches the spectrometer tube. However, since a portion passes on through the trap, a qualitative indication of its presence is possible. Point 15 records coolant, perfluorodimethylcyclohexane. In this case, ions of mass 69 are determined. In other words, instead of mere loss of an electron, the C_8F_{16} (molecular weight 400) ionizes by cleavage of the molecule. Point 13 records the combined concentration of carbon dioxide and nitrous oxide, which may find their way into the process stream by way of leaks in various process refrigerant systems (Vol. 3). The instrument cannot distinguish between CO_2 and N_2O since they have identical ionic masses, namely 44. Points 3 and 11 are used

to check the Pirani gage sample flow reading, and point 7 provides for an amplifier instrument zero check. UF_6 concentration is determined by difference. As an inherent consequence of a method utilizing subtraction of quantities, the accuracy of UF_6 determination drops sharply if the line recorder is used where the amounts of nitrogen or other diluents are large, since a one per cent error is possible in each spectrometer reading. UF_6 cannot be effectively determined where its concentration is as low as two per cent. The UF_6 content cannot be measured directly in the line recorder since decomposition of the hexafluoride sharply limits the life of the tube. A special rack is being developed at this writing, and is applicable when UF_6 concentration is so low as to cause serious error in the difference method. In this device the chemical trap is omitted; UF_6 and hydrogen fluoride are determined directly. The useful life is subject to limitation by decomposition and corrosion. Two line recorders are installed in each process or purge building in K-25 and K-27. A copper tubing manifold system is provided so that either line recorder in a given building may be valved to any cell in that building. One is usually connected to the top active cell so as to monitor the inleakage to the building. This is called the "principal" line recorder and actuates a corresponding "slave" recorder in the central control room. In this room a survey is continuously available of process stream composition throughout the cascade. The line recorder is very flexible; frequency of analysis, contaminants analyzed, range, and precision can all be varied as desired. For non-routine work the recorder program can be changed to analyze for different components, or to give more frequent analyses of a specific component. This is done, for

example, when it is desired to test for leaks with carbon dioxide as a probe gas. Such a method has been developed as an alternate to the original vacuum testing procedure (Par. 6-4) which requires shutting down, evacuating, and repeatedly purging the cell in question until it is free of process gas, and then probing with helium. The carbon dioxide method permits probing of suspected areas without shutting down the cell, and while it is in full process operation, utilizing the line recorder to indicate penetration of probe gas through a leak in the system, instead of a portable lead detector spectrometer. The method effects a great saving in the amount of process interruption time; the cell is not taken off stream for leak repair until all the preliminary work of leak location has been completed.

6-4. Leak Detector. - All previously existing methods for leak detection, such as soap bubble testing and rate-of-pressure-change methods, were completely unsuitable for use in K-25 equipment testing. It was very important to conceive and develop a radically new method which would be very accurate, very rapid, and capable of disclosing extremely small leaks. Early in 1944, experts on vacuum technology were called in to review the K-25 vacuum program. Representatives from the General Electric Company, the Westinghouse Electric and Manufacturing Company, the National Research Corporation, and the Manhattan District attended a two-day conference, at which time it was generally agreed that the Kellex design features were sound, and that the proposed testing techniques were better than any previously known methods. The problem was finally solved by development of a method involving the use of a probe gas and mass spectrometer detector. Helium was chosen as

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the probe gas because of its non-toxic nature, and extremely low molecular weight, which makes it very suitable for use where ease of penetration through small openings is desired. Furthermore, there is no possibility of clouding of test data because of traces of helium arising from other sources and existing in the equipment or ambient atmosphere.

a. Principle of Operation. - The mass spectrometer principle is used in the detector, which registers the existence of helium within evacuated equipment under test, when a stream of that gas is played externally upon an area containing a leak.

b. Component Parts. - The heart of the apparatus is a portable mass spectrometer. Auxiliaries include principally a high speed vacuum pumping system (Par. 5-10) and a source of helium gas.

c. Method of Use. - The leak detector may be considered as an ionization gage (Par. 6-3b (6)) modified so as to act as a "partial pressure gage", since, in effect, it measures the partial pressure due to helium instead of the total gas pressure. It is adjusted so as to analyse for mass 4, the helium ion. The equipment under test is continuously exhausted at high vacuum. Ambient air leaks in continuously through any leaks which may exist, but this has no effect on the instrument reading. One operator plays a stream of helium systematically over the surface of the equipment, and when the stream strikes a leak, helium penetrates into the apparatus and is swept toward the vacuum pump. A small sample of this stream is bled continuously through the spectrometer tube, and when helium enters, its ions are deflected so as to strike the collector plate, producing a plate current reading which is noted by a second operator. The location of the leak is then determined as the point currently being probed. The leak detector can

analyze for one part of helium in 200,000; it can therefore detect a leak of one micron cubic foot per hour in a typical cascade cell. The smallest detectable leak is 0.01 micron cubic foot per hour. 1/3000 of the total inleakage can be detected as a single leak. The size of a detected leak can be estimated within about fifty per cent. Accuracy down to five per cent might be obtained if the necessary care were justified by the need. The presence of UF_6 or hydrogen fluoride in the evacuated system will damage the leak detector, so that equipment to be tested must first be thoroughly purged. Over 200 of these instruments have been used at K-25, primarily during the period when newly installed equipment was being prepared and tested for process use.

6-5. Assay Machine. - The purpose of the assay machine is to determine the isotopic composition of the uranium contained in process gas samples (App. D54). A sample instrument was developed at the New York laboratory of the Kellex Corporation and turned over to the General Electric Company to serve as a model for manufacturing additional machines. A cooperative development program was undertaken by Kellex, SAM Laboratories of Columbia University, and the Carbide and Carbon Chemicals Corporation.

a. Principle of Operation. - The instrument is an adaptation of the mass spectrometer in which collector plates are positioned to receive ion beams corresponding to $U^{235}F_5$ (mass 330), and $U^{238}F_5$ (mass 333), respectively. The ratio of the corresponding ion currents is measured by means of an electronic bridge potentiometer. The isotopic assay of the sample can be computed by comparison of this ratio with that from a standard sample. At high assay values, the

isotopic ratio may be determined directly from the ion-current ratio without reference to a standard.

b. Component Parts. - The assay machine consists of a mass spectrometer and the corresponding accessories, such as adjustable leak, pumping equipment, amplifying and recording apparatus. No chemical trap similar to that used in the line recorder is used, since in this instrument, the UF_6 molecules themselves are supplied to the spectrometer for ionization and analyses.

c. Method of Use. - Two field laboratories, each containing two assay machines, are located respectively at the top and bottom of the main cascade. They are used to determine the effectiveness of separation of U-235 and U-238, and to check overall plant efficiency. Samples for assay are taken from a circulation loop in series with the line recorder manifold. The assay machine is undamaged by the presence of light gas impurities in the sample but the hexafluoride causes gradual deterioration of the source, which must be periodically replaced. Contaminating coolant, C_8F_{16}, interferes with the assay determination since it forms an ion of mass 351, which is of the same order of magnitude as the ions to be determined. The greatest source of inaccuracy in assay machine determinations is the "memory effect" which causes a low-assay sample to be erroneously reported when it immediately follows a high assay sample. The error so induced is less than ten per cent of the assay difference between successive samples, and is minimized by use of calibration standards differing only slightly from the expected process analyses. Standards are usually available within five per cent of any unknown, so that the assay machine should be accurate within 0.5 per cent. The

precision of repeated measurements is 0.6 per cent. Primary standards of calibration are not known with certainty closer than plus or minus three per cent; the results of low assay analysis are therefore relative. Using three operators for the two machines in each laboratory, seven minutes are required for assay determination from the start of sampling to the computation of results. At present, downtime for maintenance averages forty per cent of total operating time; continued improvement is expected in this situation as better techniques are developed.

6-6. Fission Counter. - The fission method of isotopic analysis of uranium was proposed by the Columbia investigators, Dunning, Booth, and Von Grosse (App. D55). For the development work at the SAM laboratories (App. D56) a gram of radium was obtained on 19 November 1943. This was used to prepare the source of neutrons needed for the test apparatus, which was completed in January 1944, and shipped to the Clinton Engineer Works for use in the K-25 plant. As with the assay machine, the purpose of the gas fission counter, the so-called "Little Gene Model", is to analyze a sample of process gas so as to measure the concentration of desired U-235 isotope. However, the fission counter is not used to analyze K-25 product; instead, two of these instruments are installed in the K-27 cascade for the purpose of measuring the amount of light isotope remaining in the tails stream leaving the plant.

a. Principle of Operation. - The method takes advantage of the tendency possessed by U-235 atoms, but not U-238 atoms, to undergo fission when bombarded by neutrons of proper kinetic energy. A spurt of positive ions resulting from an induced fission reaction can be repelled by a high potential plate to a grounded collector electrode.

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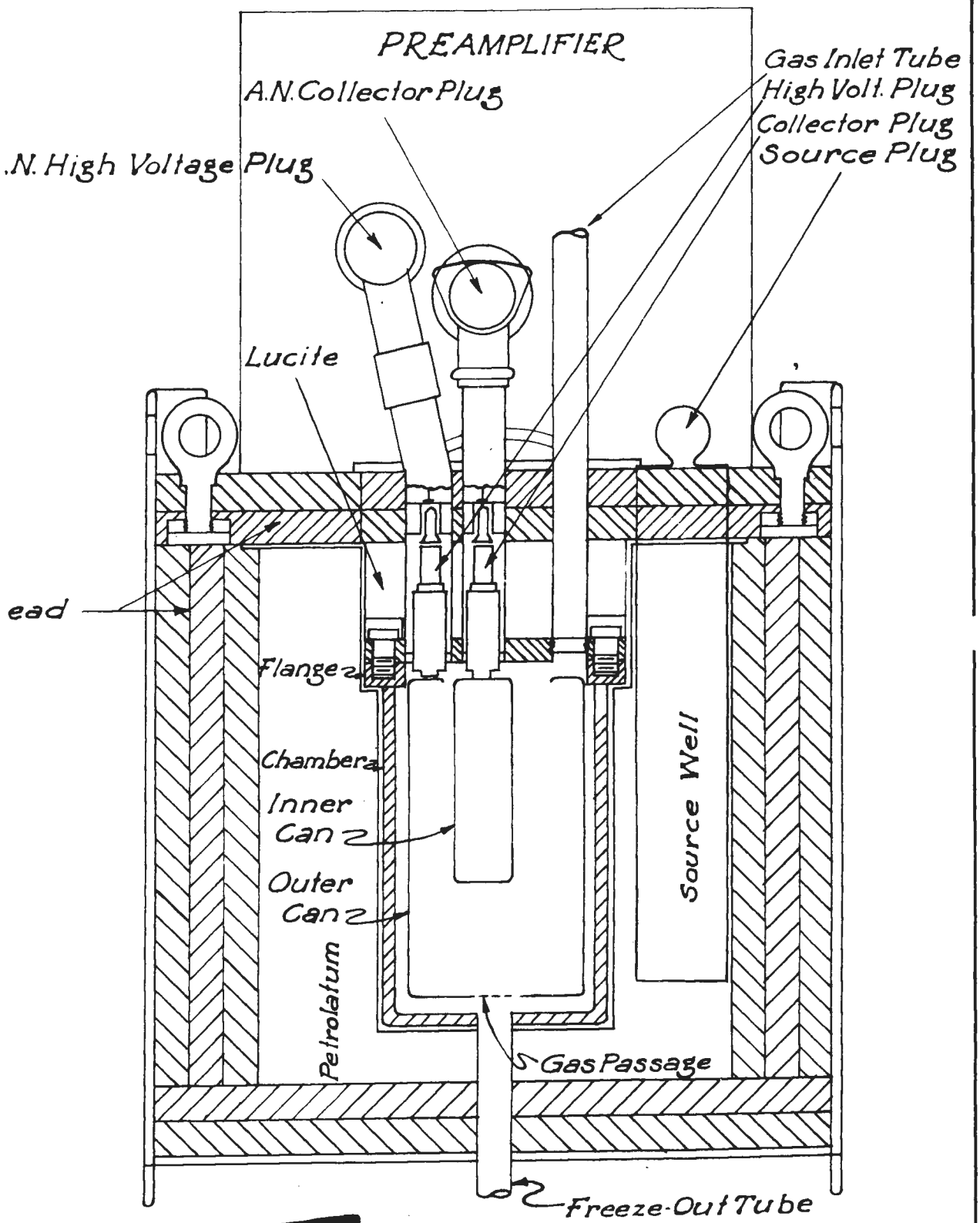


"LITTLE GENE"
GAS CHAMBER

Fig. 19

AWT

This in turn causes a momentary flow of electric current from the collector plate which, after suitable amplification, can be detected and indicated by a mechanical counter. Since the number of fission events per unit of time will increase with the concentration of U-235 in the sample, the number of ion bursts will be proportional to the isotopic concentration which it is desired to measure.

b. Component Parts.

(1) Signal Can Stand. - The stationary stand (Fig. 18) consists of an outer block of lead, and an inner layer of petrolatum. A neutron source is provided, consisting of one gram of radium mixed with beryllium. The source assembly fits into a hole in the lead block adjacent to a container for the fission chamber. A string method is provided for lowering or lifting it from the well without touching it. A quantity of hydrogenous material, such as lucite, is inserted into the well directly over the source. The fission chamber, or signal can proper, is made up of a gas chamber, suitable electrodes, and a freeze-out tube or "snout", which maintains the pressure of the process gas sample at a constant value equal to the vapor pressure of UF_6 at the temperature of an ice water bath placed around the tube. The top assembly of the ionizing chamber consists of a block of lead and a block of lucite through which are run the gas line and electrical connections to the fission chamber. The preamplifier box rests on a rubber mat on top of the stand. Figure 19 shows a simplified cross section of the signal can assembly. The signal can stand is fitted with four inches of protective lead on the sides of the radium pocket, and two inches of lead at the top and bottom. The inner layer of petrolatum serves as a

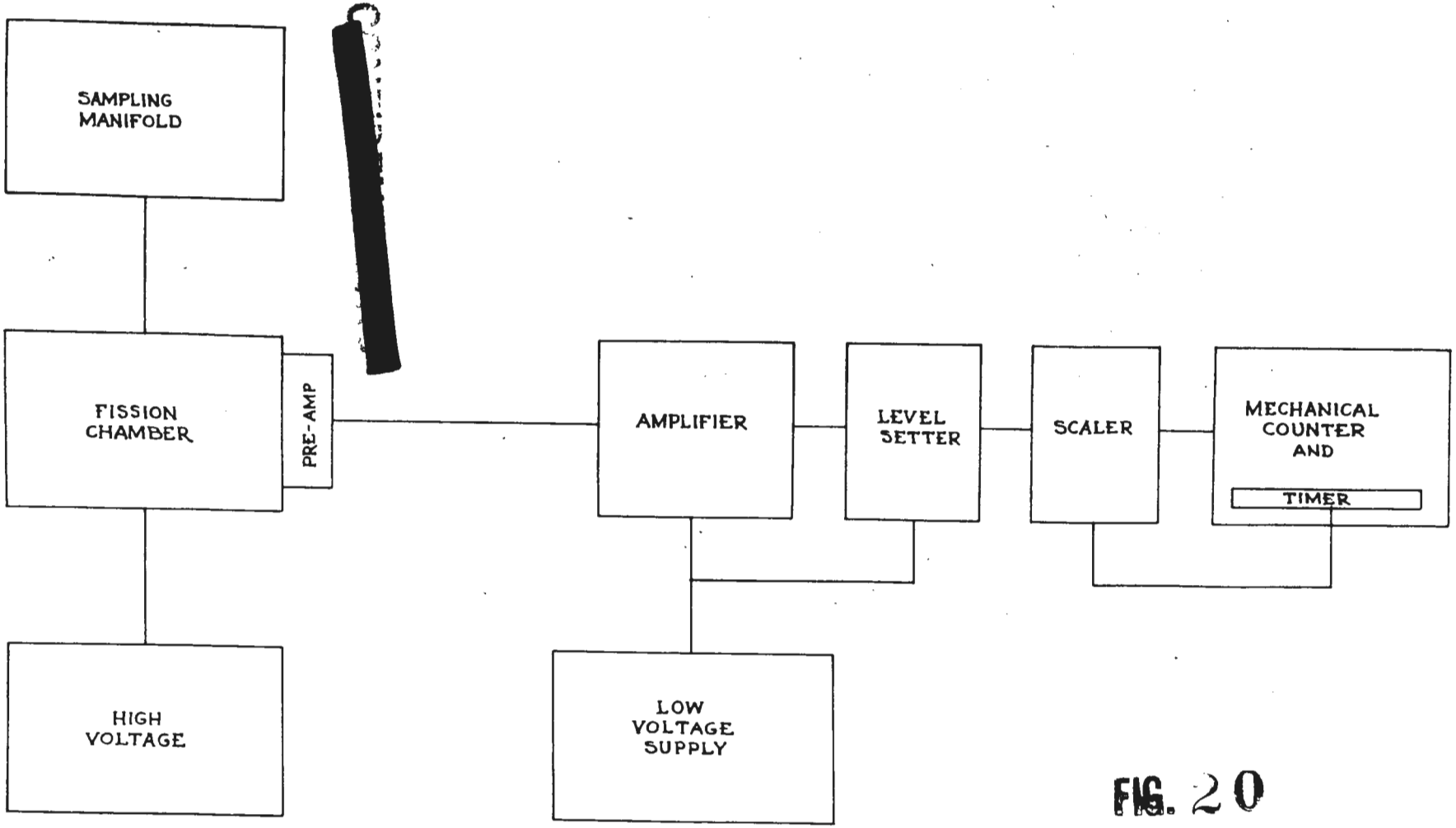


FIG. 20

"LITTLE GENE"

BLOCK DIAGRAM

neutron moderator. The total weight of the assembly is about 1600 pounds.

(2) Electrical Auxiliaries. - Figure 20 shows schematically the method of connecting the various electrical auxiliaries. A high gain alternating current amplifier panel steps up the intensity of the fission pulses. A level setter panel is provided to cut out all electrical pulses below a specified voltage level. The purpose of this accessory is to allow only those pulses to register which are due to fission (these are of a much higher voltage level), since it is not desired to count pulses due to ordinary non-fission radioactive decay. The necessary high and low voltage panels are also provided.

(3) Scaling Circuit. - The purpose of the scaling circuit is to provide a means of scaling down, or dividing the rate at which pulses are fed to the mechanical counter, so that the relatively slow time response of the counter will not limit the rate of pulse counting possible. Scale factors of 2, 4, 8, 16, 32, 64, and 128 are available.

(4) Counter and Timer. - The timer automatically cuts off the scaling circuit when a pre-set time interval has elapsed. A rather large time interval is required since the occurrence of fission is a statistically random event. In practice, the timer ordinarily is set to cut off after a run of eight minutes.

(5) Sampling Manifold Control Rack. - This serves to introduce into the signal can a process gas sample from the line recorder manifold, or a standard sample for purposes of calibration. It is also used to evacuate the signal can.

c. Method of Use. - The signal can chamber is evacuated

[redacted] [redacted]

to five microns or less, and then charged with process gas to a pressure of 18 to 19 millimeters of mercury. A small amount of the material is frozen down in the snout, by touching with a thin slush of dry ice and trichlorethylene so as to produce a pressure in the can of 17.6 millimeters. A thermos flask of ice water is then placed around the freeze-out tube, and the pressure in the signal can is controlled to plus or minus 0.002 p.s.i.a. Neutrons are emitted by the beryllium of the source as a result of its incessant bombardment by alpha radiation from the radium. The velocity of these neutrons is moderated, by passage through the petrolatum, to a value suitable for causing fission in the U-235 atoms bombarded within the sample container. The counter is set to zero, the timer adjusted for the interval desired, the scale factor selected, and the timer started. Unless the counter begins to register at about one to two counts per second, it is stopped, and the scale factor changed. The counter is read after each of a series of eight minute runs. The ice water bath is removed after five runs, the voltage shut off, and the signal can evacuated. The instrument has an accuracy of about 0.5 per cent. High concentrations of UF_6 result in the deposition of fissionable material on the internal surfaces of the can. This deposit causes a "background" signal which is superimposed upon the signal being counted. The background is therefore checked regularly and applied as a correction to all readings.

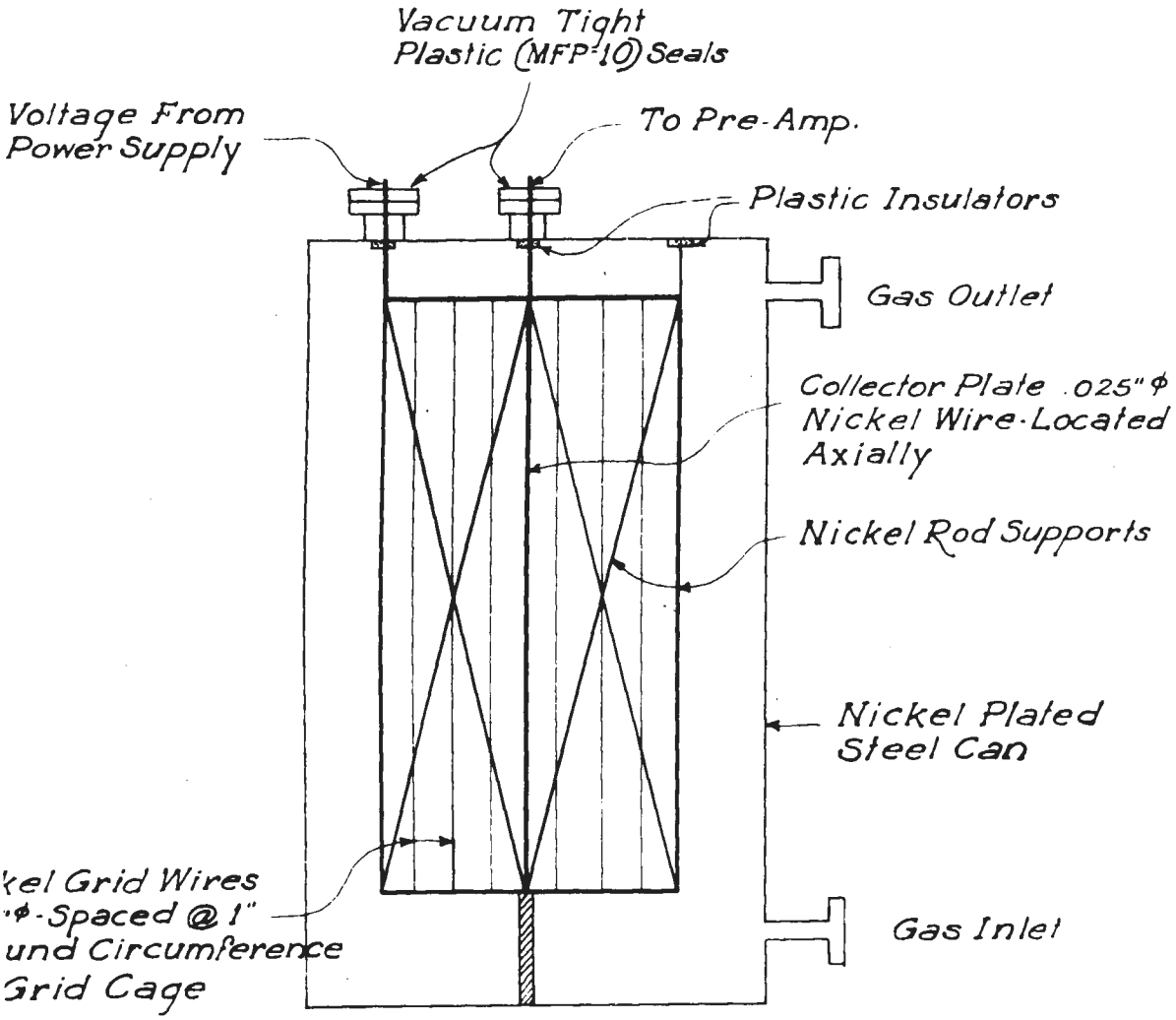
6-7. Space Recorder. - The problem of analyzing the gas in the purge cascade is complicated by the fact that the composition varies greatly from one end of this section to the other between the limits of nearly pure uranium hexafluoride and nearly pure nitrogen. The line

[redacted]

recorder is designed to analyse process gas containing relatively small amounts of impurities. To supplement the use of the line recorder in the purge cascade, it became necessary to develop an instrument which was termed the "space recorder". Its purpose is to give accurate indications of very low UF_6 concentrations to permit control of the purge rate, and to check loss of high assay product to the carbon traps.

a. Principle of Operation. - Uranium is a naturally radioactive element. Each of its three isotopes undergoes radioactive disintegration at a spontaneous and distinct rate, one result of which is the emission of high energy alpha particles. If a sample of process gas is admitted to a test chamber equipped for measuring the total rate of alpha particle emission, the result obtained will depend on both the total amount of uranium contained in the sample, and its relative distribution among the three natural isotopic forms: U-234, U-235, and U-238. The space recorder effects a measurement of total alpha emission, and in order to convert this quantity to a figure which will express the concentration of UF_6 in the diluent-containing process stream, it is necessary to know the isotopic constitution of the UF_6 present, and the individual rate of radioactive decay exhibited by each isotope. The actual operation of the space recorder (i.e., the measurement of total alpha radiation) depends upon the principle of gas ionization. High velocity alpha particles colliding with gas molecules, ionize the latter, causing them to become positively charged. The ions can be repelled by a positive grid and attracted to a negative wire, where they become discharged by taking up electrons. The result is a flow of electric current from the collector wire which is proportional to the number of

[redacted]



Can Diameter 12" Grid Cage Diameter 8"

Can Length 24" Grid Cage Length 19"

SPACE RECORDER

Signal Can

Construction

FIG. 2.1

[redacted] [redacted]

ions formed, and therefore, to the number of alpha particles emitted by the uranium in the sample. The ion current reading taken from the recording instrument can be converted into per cent UF_6 present in the gas sample by multiplying by a factor which, for a given temperature, is a function only of the isotopic constitution of the uranium in the process gas. It is interesting to note that the U-234 isotope plays a dominant role in determining this conversion factor, notwithstanding the fact that it is present in the total uranium to such a relatively minor extent (e.g., 0.006 atom per cent in normal feed material as against 0.714 per cent for U-235, and 99.28 per cent for U-238). This is due principally to the fact that the radioactive decay constant* for U-234 is about 2000 times that of U-235, and about 20,000 times that of U-238. Furthermore, at the top of the main cascade, or in the purge cascade where the space recorders are used, the uranium is highly enriched in concentration of both the light isotopes. Thus U-234, being slightly lighter than U-235, will enrich at least as much as the latter, during the course of its progress from the feed point to the top of the cascade. As a result, the alpha particles emitted by the U-234, make up the vast majority of all the alpha radiation present. Finally, the number of ions produced per alpha particle emitted by U-234, is of the same order of magnitude as for the other isotopes, and in fact somewhat greater: 136,000.

b. Component Parts.

(1) Signal Can. - The signal can (Fig. 21) is an ionization chamber with an internal diameter of twelve inches and an inside length of twenty-four inches. Because of the corrosive nature of

[redacted] [redacted]

UF_6, and the consequent danger of a high background, all metal surfaces are of nickel, and a special fluorocarbon plastic (KEL-10*) is used as an insulator. The collector wire, 0.025 inches in diameter, is mounted along the axis of the can, and connects to the pre-amplifier mounted on the cover of the can, after passing through a vacuum tight disk. This disk has ten concentric grooves cut along its inner surface in order to increase the electrical leakage path. A grid structure consisting of a cylindrical case eight inches in diameter and twenty-four inches in length is mounted concentrically with the collector wire. It is made of nickel screen formed from 0.0031 inch diameter wire, and has a one inch mesh spacing. The can is held at ground potential, the collector wire at a few millivolts, and the grid at several hundred volts. Thus all positive ions formed within the grid structure are drawn to the central collector wire. All internal parts are attached to the cover of the signal can which is gasketed with an aluminum seal.

(2) Accessory Items. - The collector current passes through a pre-amplifier, thence to an output meter, and to a single point Leeds and Northrup recording potentiometer. It is equipped with alarm contacts and an extra slide wire for operation of a remote recorder. Two series-connected sylphon-sealed pumps raise the pressure from the process stream value of about 2 p.s.i.a., to 10 p.s.i.a. A rectifier and voltage regulator are provided for maintaining the grid structure at a positive potential of either 500 or 750 volts. A filter is also included to minimize fluctuations.

c. Method of Use. - Two space recorders are provided in each of the three buildings of the purge cascade. An additional slave

recorder for each purge building reproduces the readings at the central control room. Sample gas is taken continuously from the line recorder manifold, compressed to 10 p.s.i.a., passed through the ionization chamber, and returned to the process stream. Readings are recorded periodically. The accuracy of the space recorder is on the order of five per cent of the value reported. It can detect the presence of mol fractions of UF_6 in nitrogen or other gas mixtures as low as 10^{-6}. Its upper limit is set by the radioactive contamination produced in the signal can by high concentrations of uranium hexafluoride. If the instrument is cleaned frequently to minimize this background effect, concentrations as high as 80 mol per cent can be handled, but it is normally used only on gas samples containing low percentages of UF_6. Under favorable conditions (low background and high assay of U-235 isotope), the space recorder can detect one part of UF_6 in 10,000,000.

6-6. Thermal Conductance Cell. - The thermal conductance cell is another device for measuring the amount of light components in mixtures of UF_6, nitrogen, and oxygen. The units were designed and constructed by the Kellex Corporation. They are of relatively simple and inexpensive construction.

a. Principle of Operation. - The thermal conductance cell is based upon the principle that an electric current passing through a wire increases its temperature, and that the difference in temperature between the wire and the gas surrounding it reaches an equilibrium value which is dependent on the nature (and therefore the percentage composition) of the gas. Since electrical resistance of the wire is a function of its temperature, measurement of this resistance by means of a Wheat-

[redacted]

stone bridge arrangement gives an indication of the temperature of the wire, and therefore of the concentration of light diluents in the process gas.

b. Component Parts. - The thermal conductance cell (Fig. 22) is constructed from a cylindrical block of Monel metal three inches in diameter by eight inches long with two holes drilled for insertion of wire filaments. The cavity containing the shorter filament, which is used as a compensator, is sealed off with air at atmospheric pressure. A double seal is provided for the second filament which is enclosed in the process gas to be analyzed. Plastic seals are used, and held in place by brass rings. These serve the double purpose of forming a vacuum tight connection, and electrically insulating the filaments from the metal block. The cell block is inserted in a bearing bronze support which measures three inches in outer diameter and 8-1/2 inches in length, and contains four holes for cartridge heaters and a mercury thermostat. The other electrical bridge connections are also mounted on the cell block. They are made of Manganin wire wound on bakelite spools. The unit has a protective cylindrical cover, and is thermally insulated with 85 per cent magnesia pipe covering material. A self-balancing potentiometer is used to measure bridge unbalance, in conjunction with a Leeds and Northrup Micromax strip chart recorder.

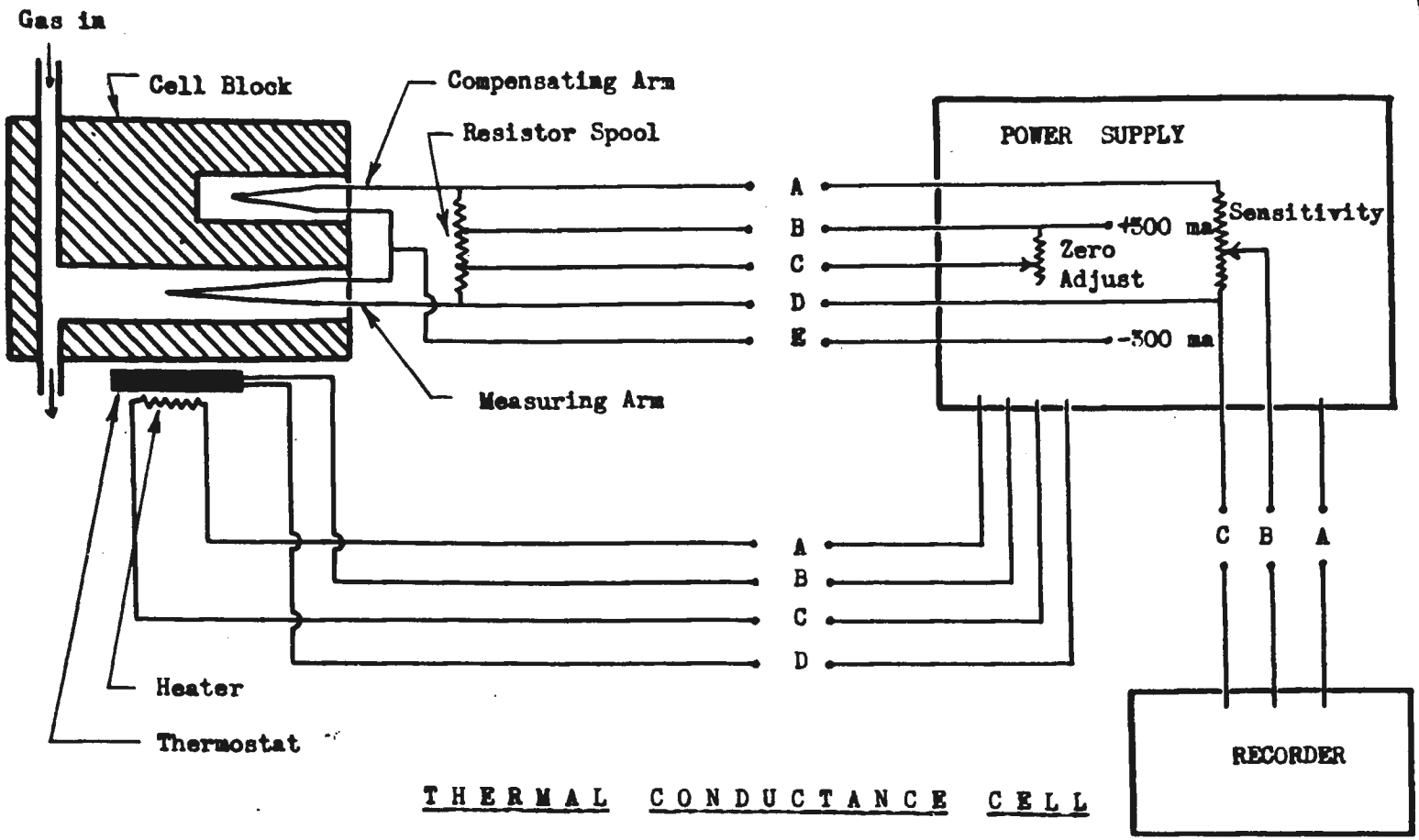
c. Method of Use. - The thermal conductance cell is used to monitor the purge rate in a normal building which is used as a top purge building during a split cascade condition. A sample of process gas is fed continuously through the unit, and an automatic reading is printed periodically on the moving chart. The instrument has an accuracy and

[redacted]

reproducibility of one mol per cent. When properly calibrated, it can be used to distinguish between any two components, or groups of components, with widely different thermal conductivity. Cells in use are calibrated for UF_6 vs. oxygen-nitrogen mixture. The usual range of the instrument is from 0 to 100 per cent of diluents, with an accuracy of one mol per cent throughout the range. The relative error involved is therefore least at highest concentrations.

6-8. Acoustic Gas Analyser. - The function of the acoustic gas analyser, which is used in the purge cascade, is to determine, indicate, and record the volumetric concentration of light diluents in the process stream, and to actuate a control mechanism so as to prevent overloading of the purge cells because of increased UF_6 concentration in the process stream being fed to a purge building. The instrument was first investigated by the Kellex Corporation; later development and manufacture were handled by the General Electric Company.

a. Principle of Operation. - The natural frequency of an acoustic resonator is a function of the physical properties of the gas contained within the resonating chamber. Visualising a cylinder with a metallic diaphragm at each end, it is possible to excite one of the diaphragms by means of an adjacent alternating current electromagnet. Vibration of this diaphragm will then set up sound waves which travel along the cylinder and set the second diaphragm in motion. This diaphragm can then be made to induce a voltage in a second electromagnetic coil placed adjacent to it. The sound intensity, and hence the voltage induced in the second coil, is greatest at the natural frequency of resonance of the chamber. When the receiver and driver



THERMAL CONDUCTANCE CELL

Fig. 22

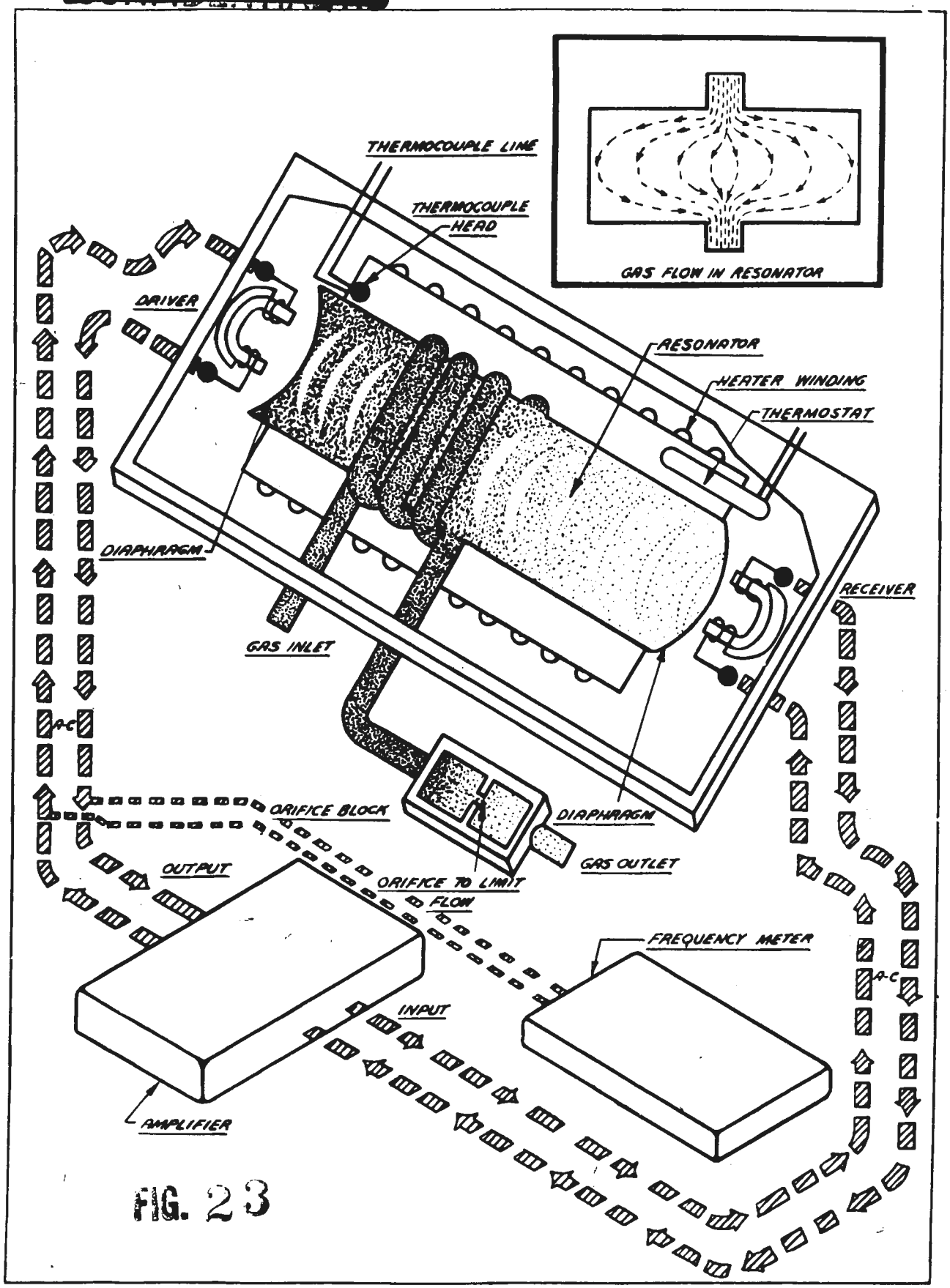


FIG. 23

PRIMARY ELEMENT, GAS FLOW AND ELECTRIC CIRCUIT DIAGRAM

[redacted] [redacted]

coils are connected respectively to the input and output terminals of an electric amplifier, the combination, under proper conditions, becomes self-oscillating at the natural frequency of resonance of the gas column.

b. Component Parts.

(1) Primary Element. - Referring to Figure 23, the primary element consists of a resonance tube containing a diaphragm at each end. Behind each diaphragm, there is provided an electromagnetic pole structure. The electromagnet coils are known as the "driver coil" and "receiver coil", respectively. The diaphragms are magnetically coupled to the pole structures, and between each diaphragm and its pole tip there is placed a rigid isolating plate which confines the gas mixture to the resonance chamber and the small space between the diaphragm and isolating plate. One diaphragm is excited electromagnetically by the driver coil, and is caused to send out sound waves which travel through the cylindrical chamber containing the gas to be analyzed, strike the second diaphragm, and cause it to vibrate. The vibration of this second membrane then induces a voltage in the receiver coil. The temperature of the gas mixture in the resonance tube is controlled by a heater and thermostat, which form part of the primary element. The heat exchanger consists of several turns of tubing embedded in an aluminum shell cast around the resonance cylinder.

(2) Accessory Parts. - The electric signal produced in the receiver coil is sent to a modulator which also receives a standard reference frequency signal from a tuning fork oscillator. The difference in these two frequencies passes through a modulator, through

[redacted]

a filter, and through a vacuum tube frequency doubler, and is then fed into a frequency meter which produces a direct current voltage proportional to the difference in frequencies. This voltage then actuates a Leeds and Northrup recording controller. Alternating current line voltage to the power supply unit is held constant by a voltage regulator.

c. Method of Use. - The gas mixture is continuously sampled at a point below the bottom cell of the purge building, and fed to the resonance tube of the primary element. The system, consisting of the primary element and amplifier, sets up an oscillating signal at the natural frequency of the gas chamber. This is dependent upon the composition of the test gas. The controller-actuating voltage is proportional to the difference between this frequency and the frequency of the standard signal. The acoustic analyzer is connected to regulate pneumatically the setting of a control valve located in the line carrying purged gases from the top cell of the building to the UF_6 traps. It thus controls the purge rate at a proper value dependent upon the concentration of UF_6 present in the gas supplied to the building. The instrument is also connected to set off an alarm signal, if the value of the diluent concentration should reach a point outside a specified range. The instrument is entirely automatic, has a rapid rate of response, and presents an analytical result which is practically independent of gas pressure. A typical range for the acoustic analyzer would be 0 to 20 per cent of light diluents, but the range can be changed when desired. The instrument possesses an accuracy of 1 volumetric per cent, and is sensitive to concentration changes in the gas mixture of 0.2 per cent or more.

6-10. HF Analyzer. - The measurement of hydrogen fluoride concentration presents special difficulties because of its corrosive nature. Several special instruments were studied for this application, the viscosity bridge type being selected as most suitable from the point of view of complexity, cost, personnel and maintenance requirement, and time lag.

a. Principle of Operation. - The viscosity bridge is analogous to the electrical Wheatstone bridge. Long metal capillaries are used as the four resistances, process sample entering one end of the bridge at high pressure (6 p.s.i.a.), passing through two parallel pairs of "resistors", and being evacuated through traps to the atmosphere. A differential pressure transmitter and recorder is connected between midpoints of the bridge arms to indicate unbalance. A chemical trap, containing sodium fluoride to remove the HF, is inserted between the two capillaries of one branch. This results in a diminished flow through the second leg of that branch, and unbalancing of the bridge. The degree of unbalance is an indication of HF concentration.

b. Component Parts. - Four capillary legs and the differential pressure transmitter and sodium fluoride trap form the instrument proper. A conventional pneumatic recording instrument is used to present analyses in graphic form. A vacuum pump with an accessory trap is also necessary.

c. Method of Use. - The viscosity bridge HF analyzer is a semi-portable instrument, principally used to monitor the cascade for HF upflow. Total sample flow is maintained at 500 cubic centimeters per minute. The use of the instrument is limited to points where

fluorine and UF_6 concentrations are low, since these substances are also absorbed by the sodium fluoride trap. Also, the presence of UF_6 will alter gas viscosity, and therefore the rate of flow through the capillary arms. This will affect the calibration of the instrument. The sodium fluoride is changed about twice a week. The viscosity bridge will record up to ten per cent hydrogen fluoride with a relative accuracy of about 0.3 per cent. The gases are evacuated to the atmosphere after passing through a soda lime trap which absorbs the hydrogen fluoride in order to protect the pump.

6-11. Trace Indicators. - Trace indicators are used to detect extremely low concentrations of UF_6 in the atmosphere, in carbon trap effluents, in seal exhaust lines, and in purged or evacuated cells. Their principal purposes are to prevent loss of UF_6 and contamination of pumping equipment, as well as to warn of hazardous traces of uranium in the air. Three types of trace indicators have been used in the plant.

a. Principle of Operation. - Trace indicators function by exposing chemical reagents to the gas stream to be tested. The presence of UF_6 is disclosed by a characteristic coloration.

b. Component Parts. - The crystal type involves the use of salicylic acid crystals; the paper type utilizes a piece of filter paper (sometimes carrying a drop of oil), which absorbs uranium compounds. The automatic type makes use of a moving tape of filter paper impregnated with potassium ferrocyanide through which a beam of light is allowed to pass before striking and actuating a photocell.

c. Method of Use. - In the case of the salicylic acid type, the crystals are removed and compared with color standards after

[redacted]

exposure to a known flow rate of gas for a pre-determined time interval. It is suitable for the detection of UF_6 concentrations below three parts per million. The plain filter paper type is checked periodically by treatment with potassium ferrocyanide which produces a characteristic color. This is then compared with color standards. The automatic trace indicator indicates gas concentration continuously by means of the photocell microammeter. It may also be used to sound an alarm, if the concentration becomes hazardous. The first two types are semi-quantitative; the automatic type is continuous and quantitative. One part of UF_6 in 100,000,000 parts of air produce a 30 per cent scale deflection in the output meter.

6-12. Infra-Red Absorption Meter. - The infra-red absorption meter is a portable leak detector of special design, used for locating leaks of C_8F_{16} in coolant lines, drums, and process coolers. It was developed by Kellex and manufactured by Baird Associates.

a. Principle of Operation. - Perfluorodimethylcyclohexane will absorb certain wavelengths in the infra-red region. If an infra-red beam is passed through a test gas chamber and focused on a thermometer, the temperature indicated will be dependent upon the amount of infra-red radiation reaching the thermometer, and therefore upon the amount of C_8F_{16} in the chamber. However, if a lithium fluoride filter is also placed in the path of the beam, the infra-red radiation will be entirely absorbed, and the thermometer temperature will be independent of the C_8F_{16} concentration in the chamber.

b. Component Parts. - The equipment consists of a source of infra-red radiation, a measuring chamber, a pump, a lithium fluoride

[redacted]

filter, and two "bolometers" or electric resistance thermometers.

a. Method of Use. - Unlike the leak detector described previously, the infra-red absorption meter can be applied without interrupting normal operation of the coolant system. Air samples from the vicinity of suspected coolant leaks are pumped through a test chamber, and two infra-red beams from a common source are passed through the chamber, one of which is also passed through a lithium fluoride filter. Thus, the intensity of infra-red radiation striking the first bolometer is dependent upon the concentration of C_8F_{16} in the chamber, while that of the second is not. The two beams are focused, respectively, on each of a pair of bolometers connected into a Wheatstone bridge circuit. A difference in temperature between the two thermometers results from the difference in intensity of impinging infra-red radiation, and causes a difference in electrical resistance. Determination of unbalance of the bridge circuit provides a measure of the difference in resistance of the two bolometers, and therefore of the concentration of C_8F_{16} in the chamber. The infra-red absorption meter is capable of detecting the presence of four parts of C_8F_{16} per million.

6-15. Dew Point Recorder. - The dew point recorder is designed to monitor the various plant supplies of dry air and nitrogen, and to warn of excessive amounts of water vapor in the gas. Installation of such an instrument at K-25 is planned, (development and fabrication being handled by Carbide), with suitable valving for sampling from any one of the supply headers carrying the above named substances.

a. Principle of Operation. - A beam of light is reflected from a cold mirror. Condensation on the mirror face dims the intensity

of the reflected beam. Measurement of the mirror temperature required to prevent dimming of the reflected ray provides an indication of the dew point.

b. Component Parts. - The apparatus includes a glass-windowed test chamber containing a mirror continuously cooled by a refrigerant system. A source of light is provided, and a photocell connected to an electrical bridge circuit, which in turn actuates an electric heater for the mirror. A thermocouple is imbedded in the mirror and connected to a continuous recorder. No pump is required for the test gas, since the air and nitrogen lines are under pressure.

c. Method of Use. - The sample of gas to be checked passes through the test chamber and is then exhausted to the atmosphere. The photocell, which is actuated by the intensity of reflected light from the mirror, unbalances the bridge circuit when condensation tends to decrease the intensity of the reflected beam. This causes the electric heater to raise the mirror temperature, and maintain it at the dew point. This mirror temperature (i.e., the dew point for the gas under test) is detected by the thermocouple and continuously recorded.

6-14. Differential Pressure Indicator. - The purpose of this device is to measure the flow of sealant nitrogen gas to the process pump seals. The extremely small flow involved made it necessary to employ a new type of instrument developed especially for this service by the General Electric Company. The instrument is a combination flow element and differential pressure transmitter. General design principles of differential pressure indicating, recording, and controlling devices are discussed in Volume 3. This paragraph treats in particular of the

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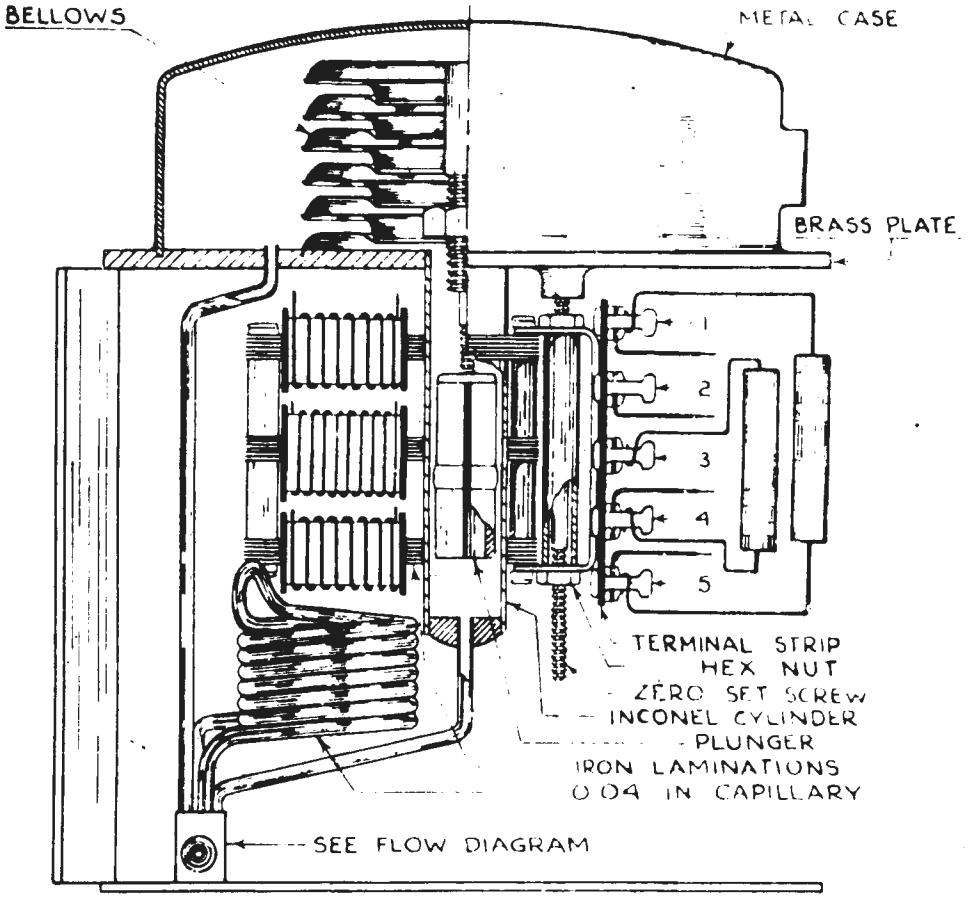
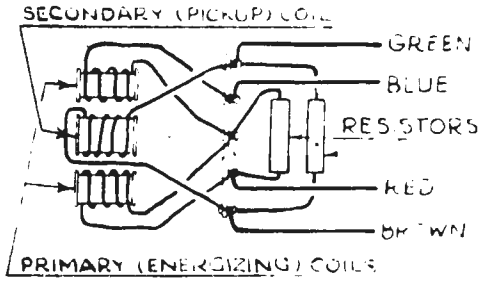
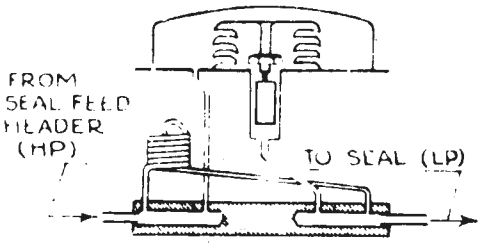
DIFFERENTIAL PRESSURE TRANSMITTER





WIRING DIAGRAM



FLOW DIAGRAM

FIG. 2 1

[redacted]

specific application of the electric differential pressure indicator, which is a more elaborate and specialized instrument, and represents the embodiment of a significant instrument research program.

a. Principle of Operation. - The differential pressure indicator determines the flow of gas by electrically measuring the differential gas pressure across an orifice of known dimensions. Variation of the differential pressure is converted, by means of a bellows arrangement, to movement of the iron core of an electromagnet, thereby inducing voltage changes which are a function of the differential pressure, and therefore of the gas flow to be measured.

b. Component Parts.

(1) Pneumatic. - Referring to Figure 24, a 36 inch capillary tube, with an internal diameter one fifth that of the gas line, is inserted in the nitrogen piping supplying sealant to the pump seal. A tap near the entrance to the capillary is connected to a chamber, under the dome of which is mounted a phosphor bronze bellows. Another tap, located at a point in the sealant piping just downstream from the capillary tube, is connected to the space enclosed by the bellows. Rigidly attached to the bellows is an iron plunger in the form of a split tube with a slight enlargement at the center.

(2) Electrical. - The plunger completes the magnetic circuit of a three-legged laminated magnetic-alloy structure. Two energizing coils, excited by a 60-cycle power source, are mounted on the two outer legs, and a pickup coil is mounted on the center leg. An amplifier is provided for stepping up the induced voltage. Centrally located on the operating panel of the control unit is an indicating

[redacted] [redacted]

wattmeter. Suitable electrical panels, and switching facilities, and an alarm system are also provided.

c. Method of Use. - A change in the gas flow rate causes a corresponding change in the pressure drop across the capillary tube. This is equivalent to a change in the differential bellows pressure, and results in movement of the bellows and plunger. Motion of the plunger disturbs the balance of the magnetic circuit. A voltage therefore appears across the pickup coil which is proportional to the bellows movement. The net induced voltage in the pickup coil is increased by an amplifier to a value suitable for operating an alarm system which would sound, for example, in the case of a process pump seal failure. The output wattmeter is calibrated in pounds per square inch with a 0 to 100 scale. A scale switch permits adjustment of the scale factor at 0.002, 0.004, 0.01, or 0.02. One differential pressure indicator is provided for each process cell. A twelve-position switch is used to connect the differential pressure indicator to the seal of any one of the twelve cell pumps. In this way, the cell can be "scanned" until the faulty seal is located. The capillary flow element acts as a choke in case of a seal failure, to restrict the flow of nitrogen to a broken seal, and prevent the failure of other seals. The capillary by-pass valve shown in the figure can be opened when it is desired to check the zero position of the bellows. Twelve potentiometers set the instrument zero respectively for each transformer pickup coil, and compensate for residual pickup voltage due to dissymmetry of the magnetic circuits at zero gas flow.

[redacted]

SECTION 7 - PILOT PLANT DEVELOPMENT

7-1. Introduction. - This section presents a description of the various pilot plant units which were built for studying and developing the operating process, and for carrying out basic research into the types and arrangements of process equipment which would be suitable for use at the K-25 plant. A number of special mechanical test loops were also set up and operated solely for testing individual pieces of equipment such as pumps, seals, and cold traps. Since these served the purpose of facilitating decisions involved in the design and manufacture of mechanical equipment, and involved no specialized process research, description of these test loops is reserved for Volume 3, Section 5. A 10-stage test cascade was also set up at the Test Floor of the Kellex Jersey City Laboratory, for the purpose of checking the soundness of certain portions of the K-25 design. It cannot be called a pilot plant in the strict sense of the word, since it was not a prototype installation operated to obtain data on which to base the process design of the full scale plant. Description of the 10-stage cascade is therefore also reserved for Volume 3. An account is presented in Volume 5 of the preliminary operation of one of the process buildings as a "54 stage pilot plant".

7-2. Single Stage Separation Systems. - The first successful separation of the uranium isotopes by the gaseous diffusion method was accomplished at Columbia University in January 1942 (App. D41).

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Isotopic analysis of the initial diffused fraction, and of the final undiffused residue, showed

changes in concentration of the light isotope ranging from 0.6 to 1.5 per cent, results which were in reasonable agreement with theoretical predictions. Improved separation systems of the same general type were subsequently constructed (App. D42) and operated in order to obtain further tests of the theory and to measure the separation performance of the various barriers. One such separating system is the "high cut tester" described in detail in a technical report (App. D43). These systems were also used to calibrate various barrier testing procedures.

7-3. Pilot Plant No. 1. - As a further means of obtaining data on barrier efficiency, and to evaluate the performance to be expected from the gaseous diffusion production plant, several pilot plants have been constructed and operated at Columbia University. These pilot plants were designed to utilise a minimum of gas, and the barrier areas were therefore very small. The first of these, called Pilot Plant No. 1 (App. C17 thru C20), utilised a barrier area about the size of a nickel; it was operated initially in October 1942. Originally located in the Pupin Laboratory of Columbia University, it was later transferred to the Nash Laboratories of the Kellex Corporation. The unit consisted of twelve sylphon-sealed pumps (App. D26), mounted in two opposing rows of six and operated from one crank shaft. It was arranged as a twelve stage cascade for total reflux with an expected isotope separation of about five per cent. In operation, the system was first evacuated and tested for air leaks. Fluorine was then admitted to about one atmosphere pressure and allowed to remain in the plant overnight in order to fluorinate or condition the surface area. The fluorine was then removed and process gas admitted. When the experiment was completed, samples were

removed from the top and bottom reservoirs for analysis. Equilibrium was established after about fifteen hours. The plant operated successfully for continuous periods as long as two hundred hours, and the total time of operation exceeded thirty-two hundred hours. Results were obtained pertaining to cascade behavior with A, DA, and MB barriers (App. D44), over a wide range of mixing and flow conditions, pressures, and pressure differentials. It also served as a means of testing instruments and other equipment for handling process gas, and furnished valuable operational experience. The then obsolescent plant was retired late in 1944, after it had served the main purpose for which it had been constructed.

7-4. Pilot Plant No. 2. - Plans and design for Pilot Plant No. 2 were initiated in December 1942, but because of unavoidable construction delays this plant was not placed in operation with process gas until 10 May 1944. The plant was a six stage total reflux cascade using reciprocating pumps of 23 cubic foot per minute displacement (App. D45, C21, C22). Type A, DA, and MB barriers were installed containing three square feet of area. DELETED DOE b(3) Complete instrumentation for automatic control was provided but manual operation was also possible. The equilibrium time was a few minutes. This six stage cascade presented the first opportunity to study the performance of barriers, instruments, and control under conditions approaching those anticipated in the large scale production plant. Many tests were run on process gas, and the plant has also furnished separation data for mixtures of nitrogen and process gas. These experiments were performed in order to study the behavior of mass spectrometer

applied to the continuous method of analysis proposed for use in the main gas diffusion plant.

a. Expansion of Pilot Plant. - In November 1944, Pilot Plant No. 2 was expanded from six to ten stages, the purpose being to increase the total separation of process gas to about three per cent of the light isotope and thus improve the precision of sample analysis. At the same time, provision was made for the use of diffuser tubes of standard plant length (seven feet) instead of the shorter ones previously used. Arrangements were also made to feed process gas into the plant at various rates up to 500 pounds per day, and to withdraw enriched material for research problems in the laboratories.

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In February 1946, the plant was dismantled and shipped to Oak Ridge, Tennessee.

7-5. Pilot Plant No. 3. - This plant was originally planned by M. W. Kellogg engineers under OSRD contract, for their laboratory in Jersey City, New Jersey. However, in the late summer of 1943, under Manhattan District supervision, it was decided at a joint meeting of Kellex and SAM representatives (App. D92) that erection and operation would be the responsibility of the SAM Laboratories personnel working in the Nash Building. However, Kellex designed the plant, procured the equipment, and supervised construction. Westinghouse gas bearing blowers were to be used in a ten stage system which was to be similar to Sections 5 and 6 of the main gas diffusion plant. As originally designed (App. D12), process gas of 36.6 per cent concentration of light isotope was to enter Section 5, and, after processing, the enriched material was to

leave at a concentration of 67.9 per cent. Section 6 received the latter material and raised the concentration to 90 per cent, which was the concentration of the final product of the plant as then envisaged. As eventually built at the SAM Laboratories, most of the Kellex design was used, but only eight stages were included. In accordance with the original Kellex plant, dummy diffusers, and steel piping and valves were to be incorporated in the plant, as it was not intended to operate with process gas but with the fluorocarbon, normal perfluoroheptane (C_7F_{16}). When experiments with the originally designed pilot plant were completed, it was intended that alterations would be made so that process gas and diffusing barriers could be introduced. As far as possible, equipment was chosen so that the conversion could be made readily. In accordance with these decisions, it has become customary to designate the original plant as No 3A and the revised plant as No. 3B.

a. Operation with Fluorocarbon - Pilot Plant No. 3A. - Difficulty in getting the special equipment for the plant (App. C23, C24) delayed its completion, and the first five stages were not placed in operation until 15 June 1944. The full plant with intersectional coupling stages and automatic control was first operated on 12 July of the same year. The cascade was operated with C_7F_{16} for a total time of 289 hours (App. D46), and during this period various disturbances, or sudden changes, in process pressure and flow were introduced in order to study the effects produced. Both manual and automatic controls were used, and at all times the plant was found to be hydrodynamically stable (App. D47). There were no serious mechanical or electrical difficulties in the cascade operation of the ten gas bearing blowers.

The mechanical behavior of the pressure transmitting and control system was also found to be satisfactory. Vacuum testing sub-assemblies were also studied and found very desirable as a means of speeding up final leak testing procedures without delaying construction. The necessity for developing special welding techniques was demonstrated; it was determined that, on the average, twenty leaks are present in 1000 feet of standard quality welds. Methods were developed for constructing vacuum tight coolers by silver-soldering the tubes to the tube sheets. It was further demonstrated that by using materials with proper density and flow characteristics, mechanical joints could be made, which would remain vacuum tight for reasonable periods.

b. Operation with Process Gas - Pilot Plant No. 5B. - Immediately upon completion of the tests outlined for Pilot Plant 5A, the necessary conversion from Pilot Plant No. 5A to 5B was made (App. C25, C26). Lack of suitable material for diffusers, which were then still in the research stage, delayed complete operation, but experiments with nitrogen and process gas in the absence of diffusers were made during the latter part of 1944. These studies gave useful information on the consumption of process gas, and on blower operation in the presence of UF_6.

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In September 1945 a unitised blower, diffuser, and cooler of SAM design was conditioned for testing. During the testing, however, leakage difficulties were encountered and few results could be obtained.

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7-8. Single Stage Blower Systems. An additional experiment was conducted at the SAM Laboratories to gain information on production plant performance using the single stage blower system.

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Conditions of pressure, cut, velocity of process gas, and value of Reynold's number were chosen to simulate a Section 1 stage of the main production plant. This system was put into operation on 5 June 1944, and, except for momentary shutdowns caused by temporary power failures, was continued until 18 July for a total operating time of about six weeks. The experiments gave important information on blower behavior, on the corrosion of metal parts exposed to process gas (App. D48), and on the plugging rate of barriers under production plant conditions (App. D49). Several other such systems were also studied using different type pumps. Very little corrosion was found in the blower, and there was no evidence of high gas velocity erosion. The performance of the tubular diffusers at plant hydrodynamic conditions was extremely satisfactory; the diffusers showed a plugging rate of less than two per cent per month.

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7-7. Vacuum Engineering School. - It was recognized at the time of the original plant design (App. D12) that complete failure of the diffusion method would result unless leakage and vacuum problems could be conquered. The degree of tightness required in the gaseous diffusion plant was without precedent in practical engineering experience. Application of the mass spectrometer for leak detecting purposes was made by A. O. Nier and his collaborators with much of the development taking place at the Nash Building under Kellex auspices. Leak detector units were constructed, personnel were trained in their use, and much of the pilot plant equipment was tested for leaks (App. C29). In February 1944, it became apparent that several hundred trained operators in addition to the already trained scientists, would be needed for leak detection work on the gaseous diffusion production plant at Clinton Engineer Works. A school for this purpose was established at the SAM Laboratories in March 1944, and over a period of about five months was attended by 221 employees (App. C27, C28, C29) of the following firms engaged in operation of the K-25 plant or manufacture of equipment for it:

Kellex Corporation
Ford, Bacon and Davis, Inc. (App. D81)
Carbide and Carbon Chemicals Corporation (App. D82)
The Crane Company (App. D83)
Allis-Chalmers Company (App. D84, D85, D86)
Whitehead Metal Products Company (App. D87)
Linde Air Products Corporation (App. D88, D89)
The A. O. Smith Corporation (App. D90)

A report on this school is available in the Manhattan District Technical Files (App. D57).

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SECTION 3 - CHEMISTRY AND PHYSICS OF THE DIFFUSION PROCESS

3-1. General Problems. - During the period from 1940 to 1942, intensive efforts were made to prepare an organic compound of uranium suitable for use in a diffusion plant. These experiments were made under OSRD prime contracts at Iowa State College, the University of Chicago, and the laboratories of the Ethyl Corporation. However, during all the course of this work, no suitable substitute for uranium hexafluoride as process gas was discovered. This compound had been known to chemists since 1909, but existing information on its chemical and physical properties was meager and, in some cases, incorrect. Its highly corrosive nature raised many problems in connection with the proposed barrier and materials of plant construction. This situation, together with the numerous other chemical problems to be expected in a large research project, led to the establishment of a chemical section at the SAM Laboratories. A vast amount of work has been done by this group on chemical aspects of the K-25 research program. Some of this work involved development and extension of existing chemical methods; much of it has been concerned with entirely new phenomena previously unknown to chemists.

3-2. Physical and Chemical Properties.

a. Physico-Chemical Studies. - Measurement and study of the chemical and physical properties of uranium hexafluoride was undertaken between 1940 and 1942. This, in turn, involved development of methods for handling the gas, and new ways of preparing it for chemical analysis. Among the physical properties investigated were the vapor

pressure, density, thermal conductivity, viscosity, heat capacity, and other thermodynamic characteristics (App. D50 through D53). Metallographic techniques were developed, using both the optical and the electron microscopes (App. D58). Reference to such work may be found in a bibliography on the subject (App. D59). A bibliography on the chemical properties of the compound is also available (App. D60).

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b. Mechanical Properties of Barriers. - The mechanical properties of barriers have been studied by the following methods:

1. Bend test, to indicate relative stiffness and ductility.
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4. Fatigue test, for information on barrier behavior under continual vibration.
5. Flutter test, for similar purposes but with smaller vibration amplitude and higher frequency (App. D61).

Without the thousands of routine examinations made by these procedures, it would probably have been impossible to produce a barrier acceptable for use in a gaseous diffusion production plant.

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C-3. Barrier Chemistry.

a. Conditioning. -

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Various pretreatment procedures for stabilizing the barrier were investigated, and it was eventually discovered that fluorination produced the desired result. The success of the stabilization procedure depended on recognition of the fact that adsorption of process gas and fluorine on a barrier was a very important problem. This in turn led to the investigation of such phenomena in considerable detail, and involved the study of surface areas and methods of measuring them. The technical results may be found in a report (App. DC3) which, in addition to giving recommended procedures for plant stabilization, includes a large amount of information on related subjects.

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b. Plugging and Consumption. - These corollary problems were also of considerable importance. The chief object, as has been explained above, was that of pre-treating the barrier in such a way that it remains stable in the presence of process gas; thus its rate of plugging must be confined within specified limits. The rate of consumption of process gas must also be minimized, especially in the higher stages of the plant where the material is highly enriched with the light isotope, and very valuable. This rate of loss has been specified in the plant design at a value not exceeding one milligram of process gas per square foot per day, and the procedures established have shown that it is possible to keep corrosion below this limit.

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All of these problems have been successfully solved.

(1) Routine Tests. - During the period when these standard procedures were being developed, the SAM Laboratories made routine tests on many different barrier samples of all types. As the A, M, W, and other barrier modifications were studied and developed, each was tested to determine whether or not it was acceptable on the basis of plugging, consumption, stabilization, and recovery. Numerous techniques for these purposes were evolved. For example, an apparatus has been constructed in which it is possible to stabilize as many as fifty 7-foot barrier tubes at once (App. D64).

8-4. Inert Gas Testing of Barriers. - In Section 7 of this volume, reference was made to the UF_6 separation testing of barriers by single stage and pilot plant methods. This method of testing barrier behavior is very slow, not only because of the time consumed in the separation experiment itself but also because of the time required for isotopic analysis. It was therefore important to devise rapid methods of measuring the separation factor of barriers. It was also necessary to determine barrier porosity by similar rapid tests. The heavy demand for routine testing prompted the Kellex Corporation to organize its own barrier testing laboratory in the Nash Building. Mechanical properties were also measured by this group.

a. Testing of Flat Samples. - A great deal of effort was expended on these procedures, with the result that suitable methods were devised for obtaining the required information rapidly. In its present

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form, the method is as follows: a flat sample of barrier is placed in a suitable holder, and a gas mixture of helium and carbon dioxide is circulated on one side of the sample; some of the gas diffuses through, and an analysis is made of the diffusate and of the undiffused gas. The separating efficiency of the barrier follows directly from these measurements. Porosity is determined by measuring the amount of gas drawn through the barrier under standard conditions of pressure and pumping rate (App. D65). The development of this rapid testing unit has been accompanied by many theoretical investigations of the physical laws of gas flow through barriers (App. D66). The results have also been compared with process gas separation tests in order to convert the results to an absolute basis. Auxiliary instruments for separation tests have been developed in order to make more precise determination of the gas mixtures diffusing through the barrier. These include thermal conductivity gas analyzers of the two different varieties (App. D67, D68). For certain special purposes, measurements of barrier separation have also been made using other gases or gas mixtures such as nitrogen-oxygen, nitrogen-perfluoroheptane and hydrogen-carbon dioxide.

b. Tube Testing. - The foregoing inert gas testing methods have all been extended so that they may be applied to tubular diffusers of standard seven-foot production plant length (App. D63) and to shorter tubes cut from them (App. D69).

8-b. Corrosion of Intermix. - The area of barrier in the diffusion plant is estimated as 90 per cent of the total area exposed to process gas, the remainder being accounted for by blowers, piping, and related equipment. It is obviously important to choose appropriate

materials of construction for these items, and to stabilise them to the process gas when necessary. A bibliography of available K-25 corrosion data has been compiled, covering the corrosive action of fluorine, hydrogen fluoride, fluorocarbons, and process gas (App. D70). Studies at the SAM Laboratories have involved development or creation of methods for measuring the corrosive effect of these gases, investigation of the fundamental chemical principles concerned, and routine tests on hundreds of different materials.

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8-6. Development of Special Chemicals. - Mention has been made in Volume 1, Paragraph 5-7, of a number of specific needs, arising within the K-25 Project, which could be successfully met only through fundamental development and technological adaptation of a number of industrially new and special chemicals, principally the process fluid itself, uranium hexafluoride; the conditioning gas, elemental fluorine; and a number of inert, highly fluorinated hydrocarbons. Description of this phase of the work, which formed a very significant branch of the chemical research program, is presented in Book VII. Further discussion is also available in the Keller Completion Report, Section III, (11).

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SECTION 9 - SAFETY AND SECURITY

9-1. Safety Program.

a. Organization.

(1) Safety Department. - The principal contractor, the SAM Laboratories, organized a Safety Department within its Industrial Relations Division. Other departments in this division dealt with employment, insurance, medical matters (physical examinations and first aid), and employee relations. These departments reported directly to the Director of Industrial Relations, and problems common to this Division were discussed and coordinated. A full-time Safety Engineer headed the Safety Division and worked directly with the various technical and service divisions of the laboratory. The normal functioning of the Safety Department required close cooperation with the Medical Division in handling injuries and taking preventive measures. The Safety Department also worked closely with the Insurance Department on compensation cases and related matters. The Columbia Area Engineer supervised the safety programs of the various contractors, and maintained liaison with the District Medical and Safety Sections.

(2) Safety Advisory Committee. - Because of the nature of the work being done, a Safety Advisory Committee was organized, consisting of scientists having direct responsibility for the activities involving hazardous operations. At times when special safety problems arose, meetings of the committee were called to discuss the situation and make recommendations to the Safety Department.

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b. Safety Measures.

(1) Employee Orientation. - All new employees were given instructions regarding their duties, at which time limits of responsibility and authority for all operations were specified. An Employees' Manual was prepared and distributed to aid in this orientation program. Safety bulletin boards were installed, and a continual poster campaign was carried on to make employees conscious of the need for careful operation.

(2) Safety Inspections. - Routine inspections were made to insure the absence of unsafe physical conditions and fire hazards, to check the condition of gas masks, and other safety equipment, and to safeguard the health of employees.

(3) Medical Facilities. - A completely equipped infirmary was established on the premises of the SAM Laboratories with two nurses on full-time, and two doctors on part-time duty. Arrangements were made with a nearby hospital to handle emergency cases.

(4) Study of New Hazards. - Prior to the inauguration of new experimental programs, conferences with scientific divisions were held to discuss possible hazards involved.

(5) Records and Statistics. - Complete records of inspections, recommendations, and investigations were maintained. Monthly reports were prepared showing the frequency and severity rates of accidents.

9-2. Security Program. - A security program was instituted in the Columbia Area, in accordance with policies established by the District Security and Intelligence Division.

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a. Organization. - The Columbia Area Security Section was headed by a special agent assigned to the area by the New York Branch Office of the Security and Intelligence Division. This man was assisted by a protective security agent. Security representatives were selected from personnel at each facility performing work of interest to the District. It was the duty of these representatives to report all appropriate matters to the Area Security Section, and to maintain proper security conditions within their facilities. Guard forces were established where necessary, and these forces reported suspicious incidents to the Security Section for action. The primary duty of the section head of the Area Security Section was to assist and advise the Area Engineer on all matters involving security and intelligence. As resident agent of the New York Branch Office, he was also required to report all significant matters to that office. Information concerning incidents pertaining to security and intelligence was also forwarded to the District Security and Intelligence Office by the Area Security Section.

b. Security Measures. - Security regulations established by higher echelons were put into effect at all facilities under the jurisdiction of the Columbia Area. Key personnel at each of these facilities were thoroughly advised of the provisions of each regulation by the Area Security Section. Periodic inspections were conducted by the head of the Security Section to insure compliance with those security regulations at each facility within the area. Security surveys were conducted by inspectors of the New York Branch Office to insure continuity of production at all Columbia Area installations.

The Security Section assisted the Area Engineer in carrying out recommendations based on those periodic surveys. No serious violation of security regulations has been reported within the Columbia Area since its establishment. At all installations, extensive use was made of visual aids supplied by the District Security Office. The Area Security Section carried out a careful personnel examination of all facilities, and reviewed security questionnaires on prospective employees prior to submitting them to the New York Branch Office for investigation.

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SECTION 10 - COSTS

10-1. Introduction. - An overall compilation of costs attributable to the K-25 Project is given in Volume 1, Section 7, together with an explanation of the principles involved in the method of cost presentation used. This section presents total costs chargeable to the research phase of the K-25 Project.

10-2. Cost Breakdown. - A detailed breakdown according to Manhattan District prime contracts is shown in Appendix A2, which also presents original and modified contract estimates. Appendix A1 presents costs incurred as the result of early work done under the auspices of the Office of Scientific Research and Development. Cost estimates for principal subcontracts are tabulated in Appendix A3.

10-3. Cost Summary. - Total cost figures for K-25 research (including the OSRD costs) effective as of the end of the fiscal year 1946 are as follows:

Contract Payments ~~to Date~~	$14,544,964
Fixed Fee Payments ~~to Date~~	0
Material Furnished by Government ~~to Date~~	471,960 (credit)
Total Contract Costs ~~to Date~~	14,073,004
Estimated Total Costs for Completed Contracts	15,811,663

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SECTION 11 - ORGANIZATION AND PERSONNEL

11-1. District Organization. - The line of authority for research and development pertaining to the diffusion plant is illustrated by Appendix B1. The activities and organization of the Madison Square Area are treated in Book VII, and of the New York Area in Book II, Volume 3.

11-2. Columbia Area. - In anticipation of the awarding of contract W-7405-eng-50 to Columbia University, Major B. K. Hough, Jr. was designated Area Engineer of the newly created Columbia Area in the early spring of 1943. By 4 August 1943, the staff of this Area consisted of 4 officers and 72 civilians (including guards). Appendix B2 presents a Columbia Area organization chart effective at this time. Major Hough was succeeded in January 1944 by Captain L. L. Grotjan who directed Area activities thereafter. The Area staff, which at the October 1944 peak (App. B3) numbered 7 officers, 178 enlisted men and 146 civilians (including 111 guards), had been reduced to 3 officers (plus 3 assigned to the Patent Advisor), 2 enlisted men, and 27 civilians by ~~30 April~~ 1 May 1946 (App. B4). Key personnel together with their functions are listed in the Appendix G1. The Columbia Area was dissolved as of 1 July 1946.

11-3. SAM Laboratories.

a. Organization.

(1) Development. - The war research activities in nuclear physics at Columbia University under OSRD contracts were organized under the name of SAM Laboratories. When contract W-7405-eng-50 was negotiated with the Manhattan District on 1 May 1943, the entire laboratory was taken over. In view of the expanded research program required under

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the new contract, additional facilities were provided in the Nash Building, New York City, shortly thereafter (July 1943).

(2) Transfer of Responsibility. - The work and equipment were gradually transferred from the Columbia University location to the Nash Building, the transfer being essentially complete by 1 February 1945. On that date, responsibility for the SAM Laboratories was assumed by Carbide and Carbon Chemicals Corporation under its contract W-7405-eng-26 (Vol. 5). The laboratory organization, which remained essentially unchanged, is depicted in Appendix B6 as of 21 April 1945.

b. Employment Statistics. - A tabulation showing the number of persons employed by the SAM Laboratories together with other Columbia Area contractors is included as Appendix B5.

c. Personnel. - The activities of the SAM Laboratories were directed until February 1945 by Dr. H. C. Urey, who was then succeeded by Dr. R. H. Crist. Dr. Urey was aided in his administrative and technical duties by Associate Directors, Dr. L. M. Currie and Dr. H. S. Taylor. Dr. J. R. Dunning directed research and development in mechanical engineering problems, pilot plants, process operations, and isotopic analysis methods. Major divisions were headed by Dr. E. T. Booth, who directed the work of all physics research groups on barrier properties and separation assay methods; Dr. H. A. Boorse, who directed the mechanical engineer groups concerned with studies of seals, blowers, pumps, and pilot plants, and by Dr. P. H. Emmett, who directed chemical research dealing with consumption, plugging, stabilization, corrosion, process materials, and fluorocarbons. Dr. Emmett was succeeded by

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Dr. W. F. Libby. Dr. F. G. Slack directed the barrier testing division, while Dr. E. Mack, Jr. was responsible for the production development of the electrofaced nickel barrier, and Dr. K. P. Cohen directed fundamental theoretical and mathematical studies of plant design and operation. Dr. [illegible] Scatchard supervised research on gas flow theory, and Dr. W. J. Creighton supervised patent work, and served as liaison officer between SAM and Decatur on BA barrier production. Dr. C. M. Murphy directed the administrative work of the patent and theoretical groups and was responsible for all technical reports, including their editing, reproduction, distribution, and custody. A detailed list of key research and development personnel of the SAM Laboratories is presented in Appendix C2.

11-4. Columbia University.

a. Organization. - As stated above, the SAM Laboratories originated in Columbia University as a consolidation of all of Columbia's Manhattan District activities. When the Carbide and Carbon Chemicals Corporation took over SAM on 1 February 1945, a certain amount of experimentation not connected with the diffusion process remained to be completed under W-7405-eng-50, and was continued under this contract independently of SAM Laboratories.

b. Personnel. - The activities of this group were guided principally by Drs. H. C. Urey, J. R. Dunning, and G. Failla. Employment statistics are furnished in Appendix B5.

11-5. Kellex Corporation.

a. Personnel. - Key research personnel of the Kellex Corporation are listed in the Appendix C5. Organization details and

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information concerning the remainder of the staff are given in Volume 8. Personnel working under Keller-supervised contracts and subcontracts are included in Volume 8, since their contributions were along the lines of manufacturing development, rather than fundamental research.

11-6. Bell Telephone Laboratories (Western Electric Company). - The Manhattan District work at these laboratories was performed under the supervision of Dr. K. B. Burns. A list of key individuals contributing to this project is attached (App. 83). Employment data are supplied in Appendix B5.

11-7. Princeton University. - The entire Princeton effort in the W-25 project was directed by Dr. H. S. Taylor, who was assisted by Dr. H. C. Joris. A list of key personnel associated in this work is presented in Appendix B4. Information regarding number of employees engaged at this facility is provided in Appendix B5.

11-8. Other Contractors.

a. Interchemical Corporation. - This work was directed by Drs. A. T. Kessler and D. M. Yans. Other key personnel working under contract W-7407-eng-25 are listed in Appendix B6. Personnel statistics may be found in Appendix B5.

b. California Institute of Technology. - This project was directed by Dr. R. M. Badger. Other key personnel engaged under contract W-7401-eng-25 are listed in Appendix B7.

c. Ohio State University. - Work at Ohio State University was directed by Dr. A. L. Henne.

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MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 2 - RESEARCH

APPENDIX "A"

CONTRACTS

No.	Title
1.	OSRD Prime Contracts.
2.	Manhattan District Prime Contracts.
3.	Subcontracts.

The following list represents a tabulation of prime research contracts attributable to the K-25 Project with the exclusion only of contracts pertaining to the special chemicals program; the latter contracts are treated in Book VII. Cost figures are effective as of the end of the fiscal year 1946. Subcontract costs are included in the prime contract figures.

Contract type is tabulated in the first column and denoted by a numerical code, the key for which is as follows:

(1) Architect-engineer services.
(2) Cost plus overhead.
(3) Lump sum service.

Method of letting is tabulated in the second column and denoted by a numerical code, the key for which is as follows:

(1) Negotiated by Columbia Area.
(2) Negotiated by District Engineer.
(3) Negotiated by New York Area.
(4) Negotiated by New York and Decatur Areas.
(5) Negotiated by Madison Square Area.

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CONTRACT NO.	NAME OF CONTRACTOR EFFECTIVE DATE	HOME OFFICE OF CONTRACTOR	SCOPE
OEMsr-106	Columbia University 1 July 1941	New York, N. Y.	Invest for s
OEMsr-406	M. W. Kellogg Company 16 January 1942	Jersey City, N. J.	Desig pilot ment, ratio
OEMsr-412	Columbia University 1 December 1941	New York, N. Y.	Separ diffu K-25
OEMsr-564	Ohio State University Research Foundation 3 August 1942	Columbus, Ohio	Prepa sampl

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NOTE: All above are cost-plus overhead contracts.
All were negotiated by the Executive Secretary, OSRD.
All contracts are completed.
Total costs are $2,397,860.

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OSRD PRIME CONTRACTS

HOME OFFICE OF CONTRACTOR	SCOPE OF WORK	ORIGINAL CONTRACT ESTIMATED AMOUNT (NOT INCLUDING FEE)
New York, N. Y.	Investigation of the diffusion method for separation of isotopes of uranium.	$ 25,000
Jersey City, N. J.	Design, construction and operation of pilot plant and development of equipment, materials and methods of operation of a large plant.	75,000
New York, N. Y.	Separation of isotopes of uranium by diffusion process; also various non K-25 projects.	297,250
Columbus, Ohio	Preparation and purification of samples of specified fluorocarbons.	10,000

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cost-plus overhead contracts.
tiated by the Executive Secretary, OSRD.
are completed.
re $2,397,860.

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ORIGINAL CONTRACT ESTIMATED AMOUNT (NOT INCLUDING FEE)	MODIFIED CONTRACT ESTIMATED AMOUNT (NOT INCLUDING FEE)	SUPERSEDED BY MANHATTAN DISTRICT CONTRACT
...ion method of uranium.	DELETED	W-7405-eng-23
...eration of ... of equip- ... of ope-		
...ranium by ...ious non		W-7405-eng-60
...n of ...carbons.		W-7405-eng-96
		W-7405-eng-142

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CONTRACT NO. TYPE	NAME OF CONTRACTOR EFFECTIVE DATE METHOD OF LETTING	HOME OFFICE OF CONTRACTOR	MANHATTAN DISTRICT PRIME CO SCOPE OF WORK
W-7401-eng-58 (1)	Voorhees, Foley-Walker, and Smith 19 July 1943 (1)	New York, N. Y.	Preparation of necessary de specifications, etc, and te supervision to convert cert premises to a research labo
W-7401-eng-62 (2)	Comstock and Wescott, Inc. 16 August 1943 (2)	Cambridge, Mass.	Research, development and i spection work.
W-7401-eng-63 (2)	California Institute of Technology 1 July 1943 (3)	Pasadena, Cal.	Conduct certain studies and experimental investigations
W-7401-eng-80 (3)	Voorhees, Foley-Walker, and Smith 4 October 1943 (1)	New York, N. Y.	Furnish necessary inspectio surveys, recommendations, a for SAM project.
W-7405-eng-50 (2)	Columbia University 1 May 1943 (1)	New York, N. Y.	Research and development of process, for separation of i uranium.
W-7405-eng-74 (2)	Purdue Research Foundation 1 May 1943 (2)	Lafayette, Ind.	Furnish facilities and pers train personnel. Conduct c studies and experimental i
W-7405-eng-92 (2)	Battelle Memorial Institute 16 April 1943 (4)	Columbus, Ohio	Conduct certain studies and investigations.
W-7405-eng-95 (2)	Ohio State University Research Foundation 1 July 1943 (1)	Columbus, Ohio	Continuation of work under C Ser-554.
W-7405-eng-98 (2)	Princeton University 1 July 1943 (1)	Princeton, N. J.	Fundamental chemical studie barriers and barrier materi

[redacted] SECRET

[redacted]

	MANHATTAN DISTRICT PRIME CONTRACTS SCOPE OF WORK	ORIGINAL CONTRACT ESTIMATED AMOUNT (NOT INCLUDING FEE)	MODIFIED CONTRACT ESTIMATED AMOUNT (NOT INCLUDING FEE)	CONTRACT PAYMENTS TO DATE (NOT INCLUDING FEE)	FIXED F PAYME TO DA
Y.	Preparation of necessary designs, specifications, etc, and technical supervision to convert certain premises to a research laboratory	$ 200,000	$ 210,600	$ 38,617	-
s.	Research, development and inspection work.	10,000	38,000	34,949	-
	Conduct certain studies and experimental investigations.	25,000	38,000	22,644	-
Y.	Furnish necessary inspections, surveys, recommendations and advice for SAM project.	1,000	1,000	1,000	-
,	Research and development of diffusion process for separation of isotopes of uranium.	7,000,000	15,000,000	10,813,523 (1,000,000 Insurance)	-
,	Furnish facilities and personnel, and train personnel. Conduct certain studies and experimental investigations.	50,000	468,000	100,744	-
	Conduct certain studies and experimental investigations.	85,000	336,000	48,000	-
	Continuation of work under contract OEMsr-554.	20,000	20,000	19,467	-
.	Fundamental chemical studies of barriers and barrier materials.	100,000	360,000	334,998	-

[redacted]

[redacted]

D D-	CONTRACT PAYMENTS TO DATE (NOT INCLUDING FEE)	FIXED FEE PAYMENTS TO DATE	MATERIAL FURNISHED BY GOVERNMENT TO DATE	TOTAL CONTRACT COSTS TO DATE	ESTIMATED TOTAL CONTRACT COSTS WHEN COMPLETED
	$ 38,617	-	-	$ 38,617	$ 38,617
	34,949	-	-	34,949	36,949
	22,644	-	-	22,644	56,816
	1,000	-	-	1,000	1,000
	10,813,523 (1,000,000 Insurance)	-	471,773 (Credit)	10,341,750	11,042,861 1,000,000
	100,744	-	-	100,744	100,744
	46,000	-	-	46,000	46,000
	19,467	-	450 (Credit)	19,017	19,017
	334,995	-	263	335,258	338,203

[redacted]

[redacted]

[redacted]

CONTRACT NO. TYPE	NAME OF CONTRACTOR EFFECTIVE DATE METHOD OF LETTING	HOME OFFICE OF CONTRACTOR	MANHATTAN DISTRICT PRIME C SCOPE OF WORK

DOE
b(3)

DELETED

[redacted]

[redacted]

[redacted]

PRIME CONTRACTS	ORIGINAL CONTRACT ESTIMATED AMOUNT (NOT INCLUDING FEE)	MODIFIED CONTRACT ESTIMATED AMOUNT (NOT INCLUDING FEE)	CONTRACT PAYMENTS TO DATE (NOT INCLUDING FEE)	FIXED PAY TO DA
DELETED				
SUBTOTALS (DISTRICT CONTRACTS)		12,147,104		0
OSRD CONTRACTS		2,397,860		0
GRAND TOTALS		14,544,964		0

DOE b(3)

[redacted]

[redacted]

L ACT ATED T CLUD- E)	MODIFIED CONTRACT ESTIMATED AMOUNT (NOT INCLUD- ING FEE)	CONTRACT PAYMENTS TO DATE (NOT INCLUD- ING FEE)	FIXED FEE PAYMENTS TO DATE	MATERIAL FURNISHED BY GOVERN- MENT TO DATE	TOTAL CON- TRACT COSTS TO DATE	ESTIMATED TOTAL CON- TRACT COSTS WHEN COMPLETED
DELETED						
NTRACTS)	12,147,104	0		471,960 (Credit)	11,675,144	13,413,808
	2,397,860	0		0	2,397,860	2,397,860
	14,544,964	0		471,960 (Credit)	14,073,004	15,811,668

DOE b(3)

[redacted]

[redacted]RD SECRET

CONTRACT NO.	NAME OF SUBCONTRACTOR	HOME OFFICE OF SUBCONTRACTOR
W-7405-eng-60		
S. C. 3	Cornell University	Ithaca, N. Y.
DELETED		DOE b(3)
S. C. 13	University of Wisconsin	Madison, Wisc.
DELETED		DOE b(3)
S. C. 31	General Electric Company	Schenectady, N. Y.
S. C. 50	Battelle Memorial Institute,	Columbus, Ohio
OEMsr-412		
S. C. 49	American Machine Defense Corporation	Brooklyn, N. Y.
S-12128	Elliott Company	Jeanette, Pa.
563,371	General Electric Company	Schenectady, N. Y.
564,231	Interchemical Corporation	New York, N. Y.
DELETED		DOE b(3)
113	Ohio State University Research Foundation	Columbus, Ohio

NOTE: W-7405-eng-60 subcontracts were negotiated by t
OEMsr-412 subcontracts were negotiated by the C

[redacted]

SECRET

[redacted]

SUBCONTRACTS

PICE OF NTRACTOR	SCOPE OF WORK	ORIGINAL CONTRACT ESTIMATED AMOUNT (NOT INCLUDING FEE)	M (I
N. Y.	X-ray studies of uranium hexafluoride.	$ 5,000	$
	DELETED		
, Miss.	Classification by centrifuge of nickel carbonates.	5,000	
	DELETED		
tady, N. Y.	Development of magnetic cloth and special lubricants and insulating materials for process pumps.	7,445	
s, Ohio	Application of known commercial electro-polishing methods of barrier panels.	5,000	
	SUBTOTAL:		
a, N. Y.	Development of engineering designs for special pumps.		
s, Pa.	Development of positive clearance seal for centrifugal compressor.		
tady, N. Y.	Develop new types of pumps for handling uranium hexafluoride.		
r, N. Y.	Develop methods for commercial production of nickel powders for barriers.		
	DELETED		
, Ohio	Preparation of samples of specified fluorocarbons.		
	SUBTOTAL:		

DOE b(3)

DOE b(3)

DOE b(3)

egotiated by the Contractor and approved by the District Engineer.
iated by the Contractor and approved by the Executive Secretary of OSRD.

[redacted]

	ORIGINAL CONTRACT ESTIMATED AMOUNT (NOT INCLUDING FEE)	MODIFIED CONTRACT ESTIMATED AMOUNT (NOT INCLUDING FEE)	ESTIMATED TOTAL CONTRACT COSTS WHEN COMPLETED
f uranium hexafluoride.	$ 5,000	$ 5,000	$ 5,000
DELETED			DoE b(3)
by centrifuge of es.	5,000	5,000	5,000
DELETED			DoE b(3)
agnetic cloth and special insulating materials for	7,443	7,443	7,443
known commercial electrode of barrier panels.	5,000	5,000	5,000
SUBTOTAL:			48,257
ngineering designs for			
positive clearance seal compressor.			
s of pumps for handling ride.			
for commercial production s for barriers.			
DELETED			DoE b(3)
amples of specified			
SUBTOTAL:			64,150

wed by the District Engineer.
by the Executive Secretary of OSRD.

[redacted] SECRET

MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 2 - RESEARCH

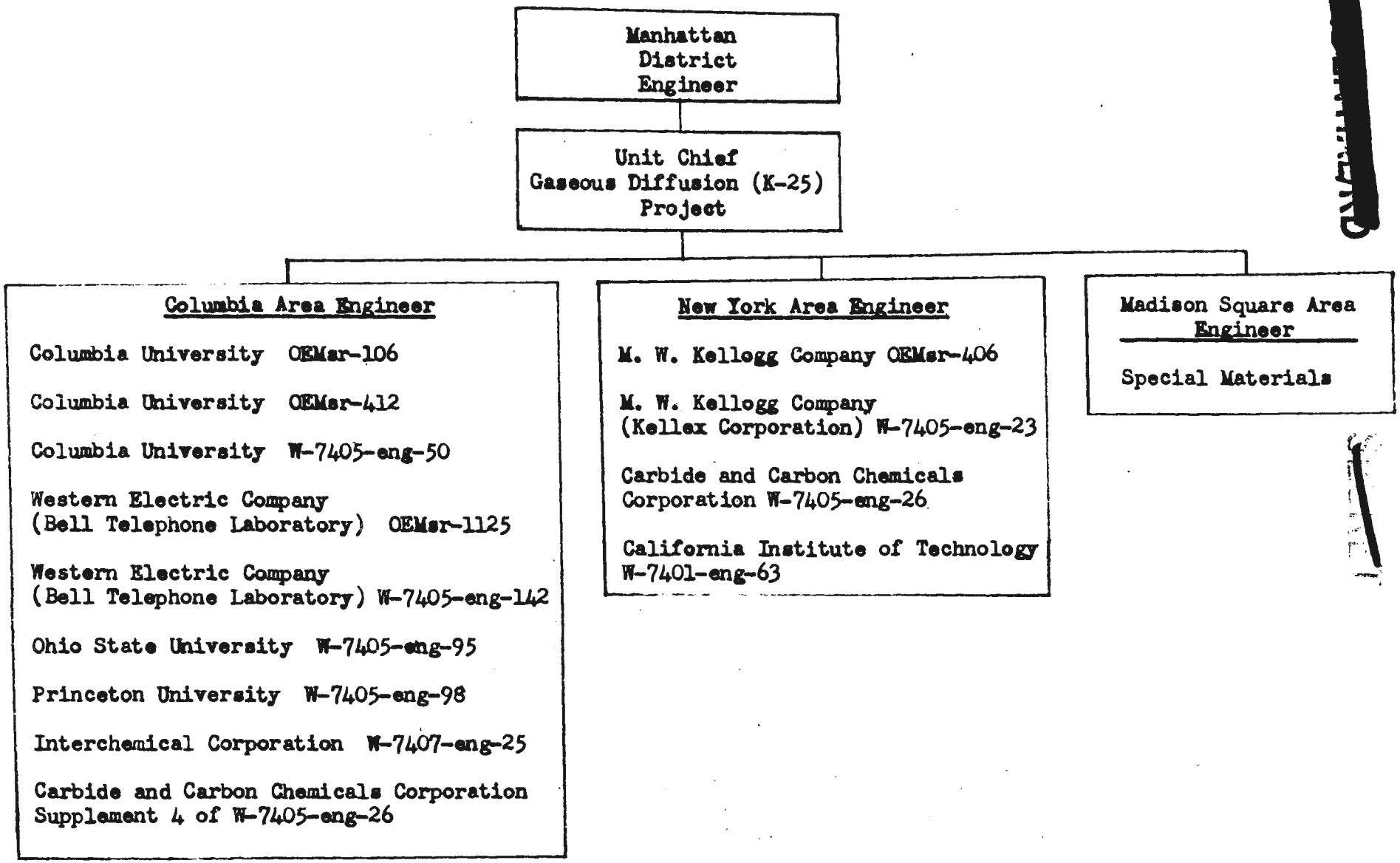
APPENDIX "F"

CHARTS

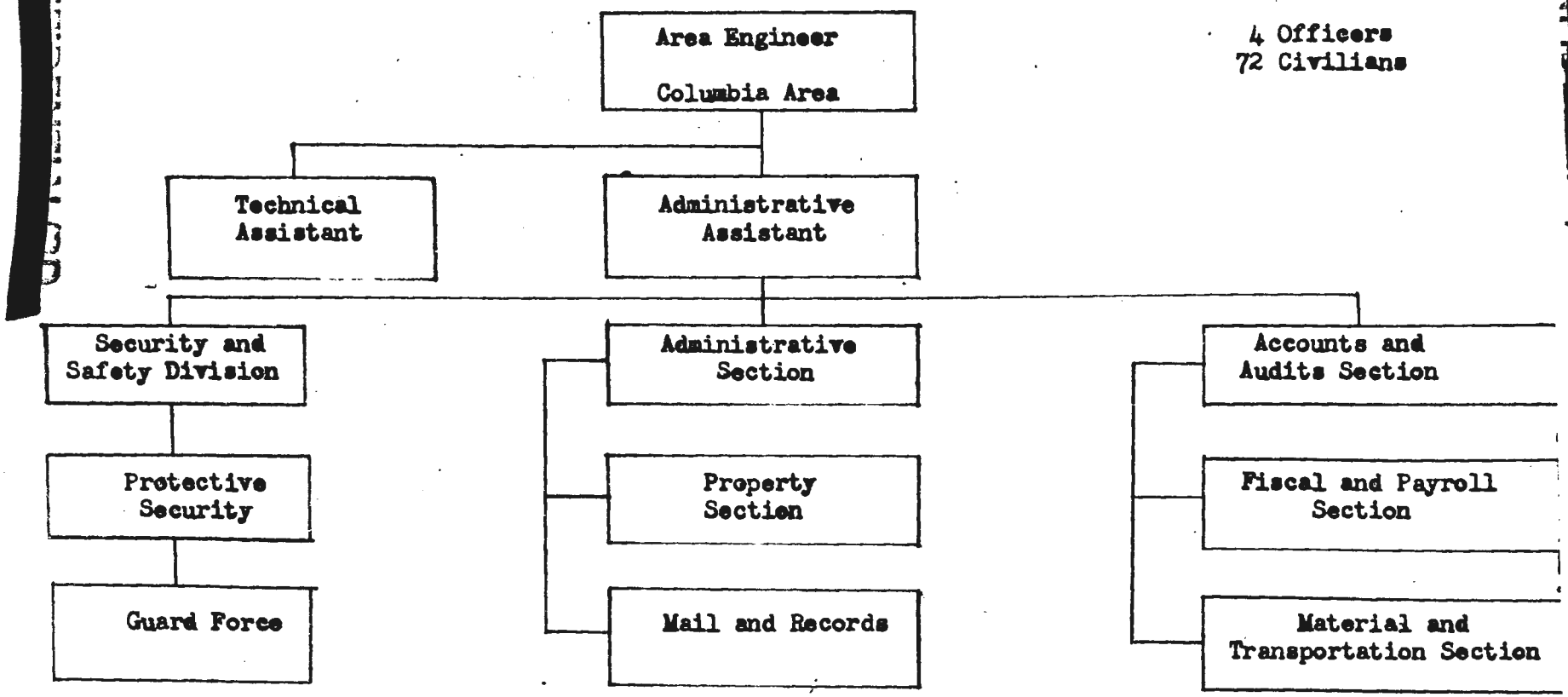
No.	Title
1.	Line of Authority for Research and Development on Gaseous Diffusion (K-25) Project.
2.	Organization Chart, Columbia Area, 4 August 1945.
3.	Organization Chart, Columbia Area, 5 October 1944.
4.	Organization Chart, Columbia Area, 1 May 1945.
5.	Employment Growth, Columbia Area K-25 Contractors.
6.	Organization Chart, SAM Laboratories, Carbide and Carbon Chemicals Corporation, 21 April 1945.

[redacted]

SECRET



Line of Authority for Research and Development on Gas Diffusion (K-25) Project



Organization Chart

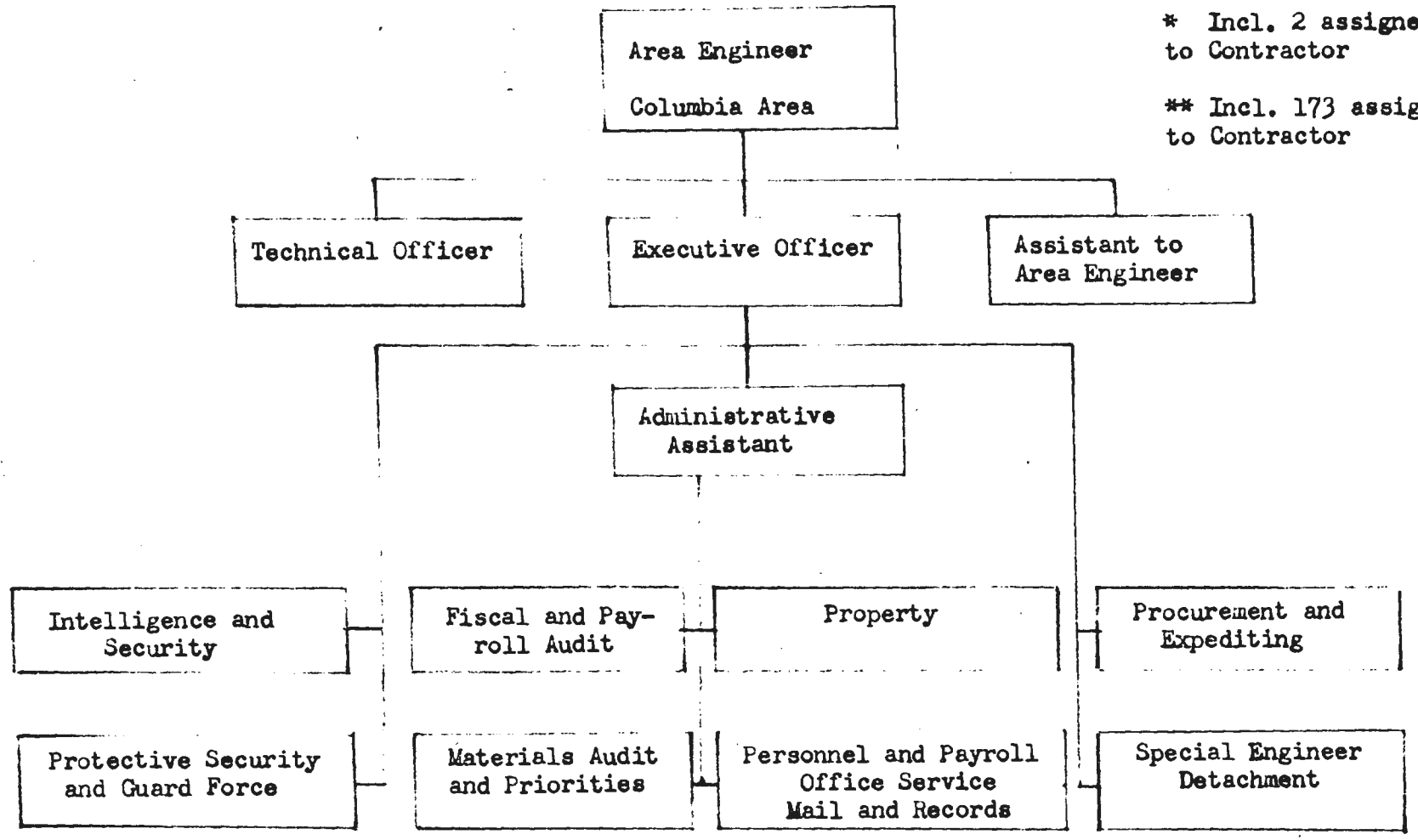
Columbia Area

4 August 1943

146 Civilians

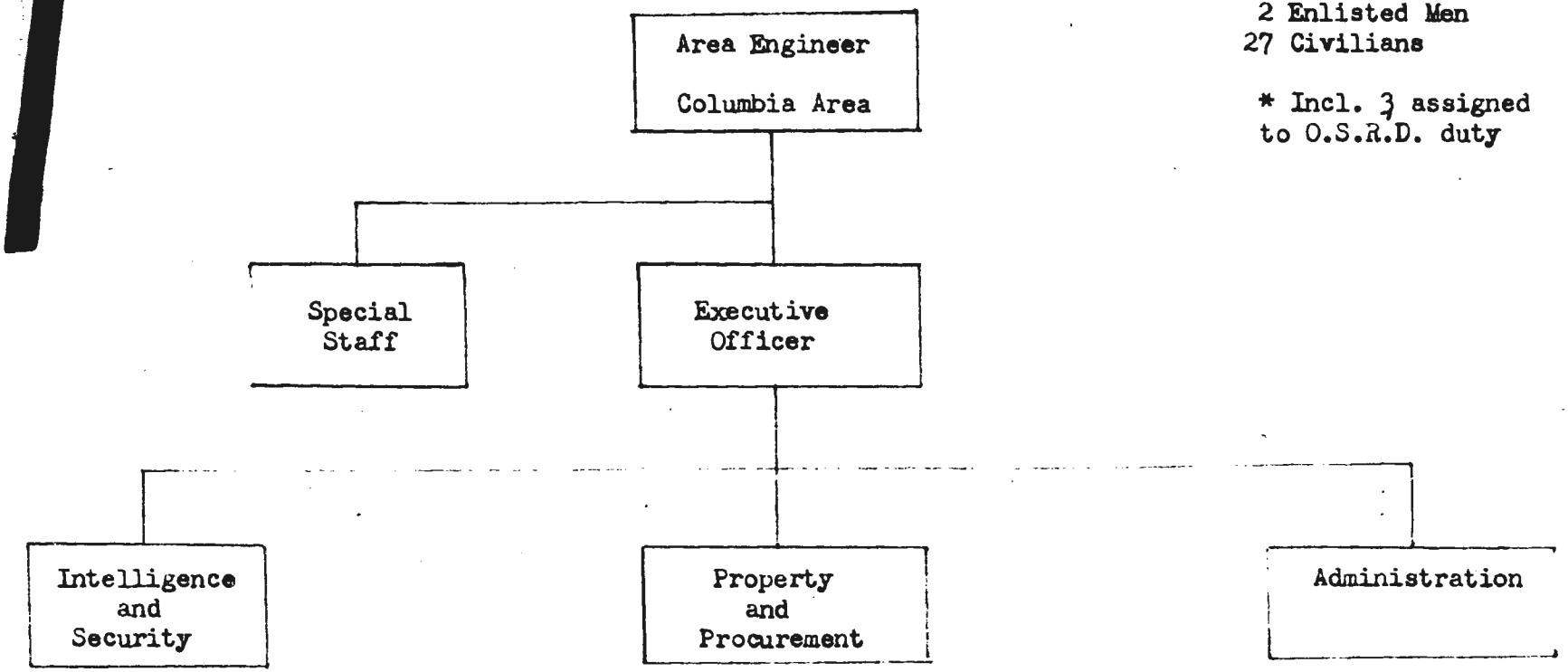
* Incl. 2 assigned to Contractor

** Incl. 173 assigned to Contractor



Organization Chart
Columbia Area
5 October 1944

B3



6 Officers*
2 Enlisted Men
27 Civilians

* Incl. 3 assigned to O.S.R.D. duty

Organization Chart
Columbia Area
1 May 1946

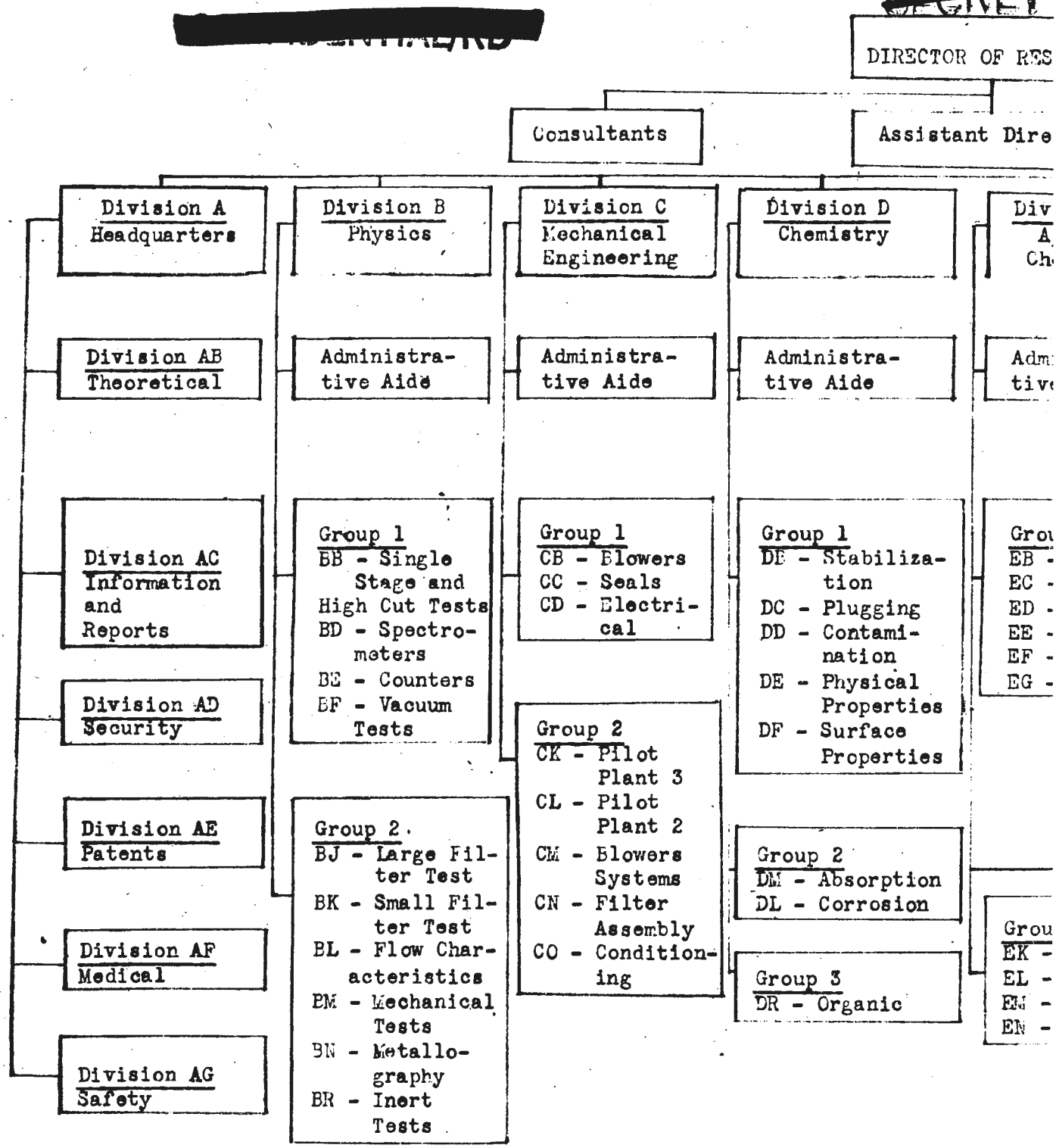
	June 1944	July 1944	Aug. 1944	Sept. 1944	Oct. 1944	Nov. 1944	Dec. 1944	Jan. 1945	Feb. 1945	Mar. 1945	Apr. 1945	May 194
Columbia University (SAM)	979	984	981	1063	1034	996	950	902	-	-	-	-
Carbide and Carbon Chemicals Corporation (SAM)	-	-	-	-	-	-	-	-	837	819	834	84
Western Electric Company	31	18	16	18	14	8	12	8	6	4	2	1
Princeton University	30	31	31	29	33	30	31	30	31	25	25	2
Interchemical Corporation	21	14	6	9	-	-	-	-	-	-	-	-
Ohio State University	8	-	-	-	-	-	-	-	-	-	-	-

	June 1945	July 1945	Aug. 1945	Sept. 1945	Oct. 1945	Nov. 1945	Dec. 1945	Jan. 1946	Feb. 1946	Mar. 1946	Apr. 1946
Carbide and Carbon Chemicals Corporation (SAM)	819	834	745	649	640	585	563	550	516	452	444
Western Electric Company	1	1	1	1	-	-	-	-	-	-	-
Princeton University	25	25	25	26	26	24	21	11	5	4	-

Employment Growth

Columbia Area K-25 Contractors

[redacted]



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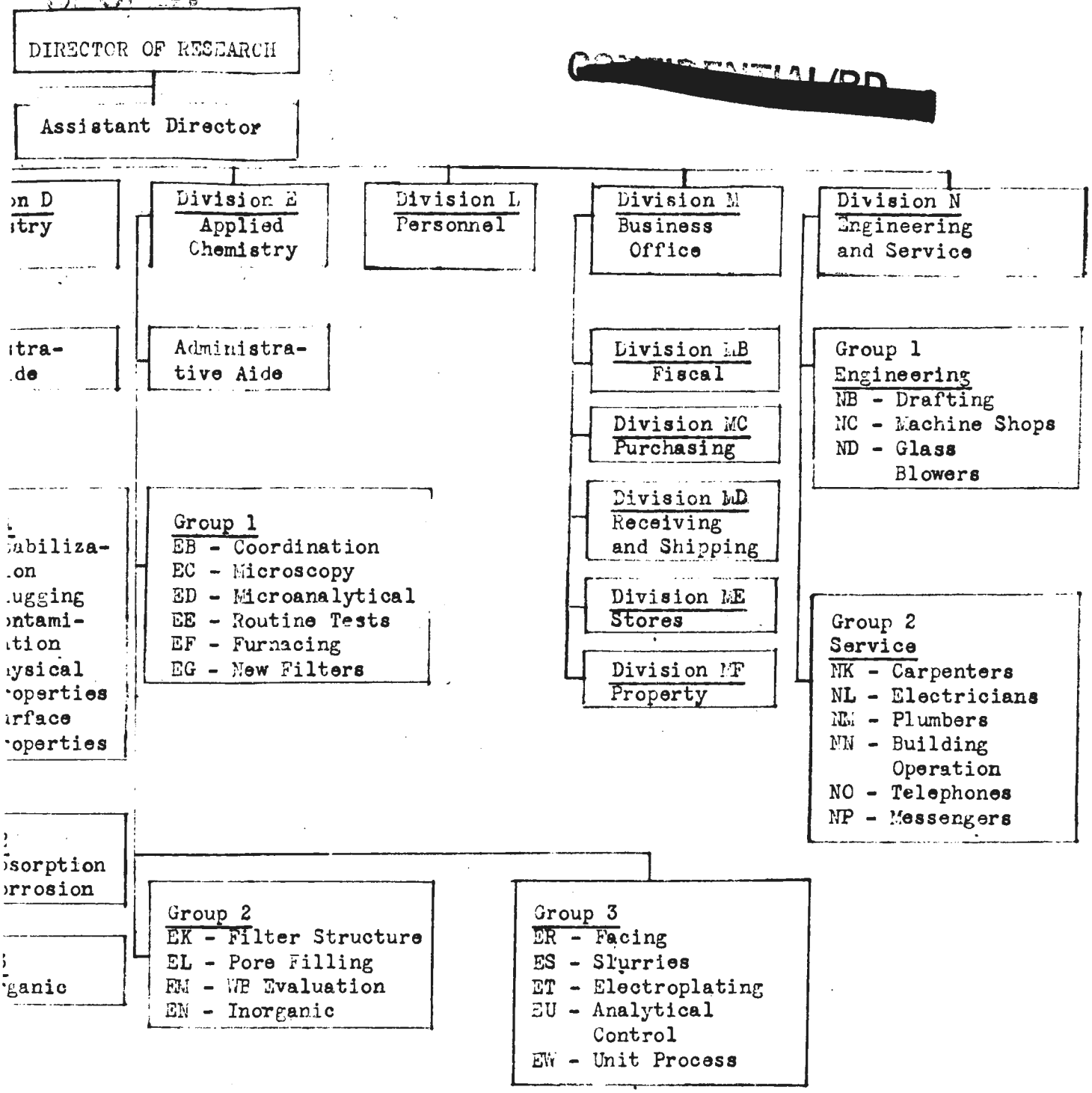
B6

SECRET

CONFIDENTIAL/RD



Organization Chart
SAM Laboratories
Carbide and Carbon Chemicals Corporati
Contract W-7405-eng-26 (Supplement 4
21 April 1945

CONFIDENTIAL/RD

SECRET

[redacted]

MANHATTAN DISTRICT HISTORY

BOOK III - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 2 - RESEARCH

APPENDIX "C"

PHOTOGRAPHS

No.	Title
1.	Hydrogenation Furnace with Heating Ball in position, as operated at the Schermerhorn Pilot Plant for Heat Treating Barrier.
2.	Interior view of Hydrogenation Furnace with a Reel of Barrier Material in place.
3.	
4.	DELETED
5.	
6.	
7.	
8.	
9.	DELETED
10.	
11.	
12.	

DOE b(3)

DOE b(3)

[redacted]

[redacted] SECRET

No.	Title
13.	
14.	DELETED DOE b(3)
15.	Gas Bearing Blower.
16.	Westinghouse Model CS-V Gas Bearing Blower.
17.	Front View of Pilot Plant No. 1 (Code Name: Gertrude).
18.	Rear View of Pilot Plant No. 1.
19.	Pilot Plant No. 1, showing a front view of the Twelve-Stage Cascade as first assembled in the Pupin Physics Laboratories of Columbia University.
20.	Pilot Plant No. 1, showing a rear view of the original Twelve-Stage Cascade with Type B Pumps mounted as a Common Crankshaft.
21.	Rear view of Pilot Plant No. 2, showing three Type W Pumps.
22.	Interior View of Pilot Plant No. 2, showing Diffusers and Pressure Transmitters.
23.	Pilot Plant No. 3A, showing a view of the Main Instrument Panel.
24.	Rear view of Pilot Plant No. 3A, showing the four Top Stages, and (in the foreground) the Motor Coolant Circulating System.
25.	Pilot Plant No. 3B, showing Stages 2, 4, and 6, Type CS-V Gas Bearing Blowers, Blower Repressuring System, Whitehead Diffusers, Surge Drum, and Heat Exchangers.
26.	Pilot Plant No. 3B, showing Stages 1, 3, and 5, Blowers, Diffusers, Control Instruments, and Sampling Manifolds.
27.	View of Vacuum Engineering School, showing Students examining Electronic Equipment used in Leak Detecting Apparatus.
28.	Vacuum Engineering School, showing a Leak Detector and and a Pumping Wagon being assembled.

[redacted]

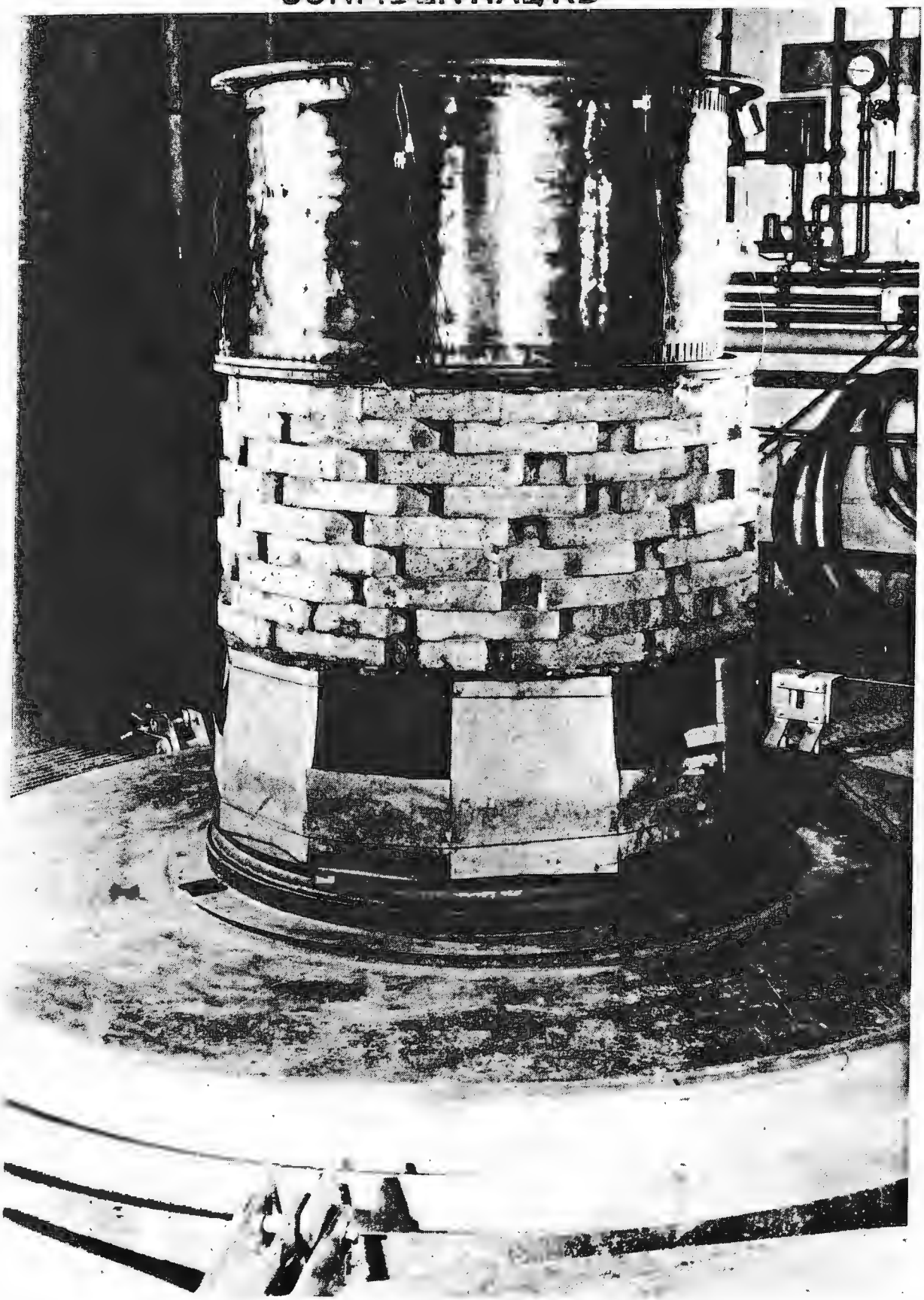
[redacted] SECRET

No.	Title
29.	Vacuum Engineering School, showing the Mass Spectrometer Leak Detector.

[redacted]

[redacted]

C1 Hydrogenation Furnace with Heating Bell in position, as operated at the Scharmerhorn Pilot Plant for Heat Treating Barrier.



[redacted]

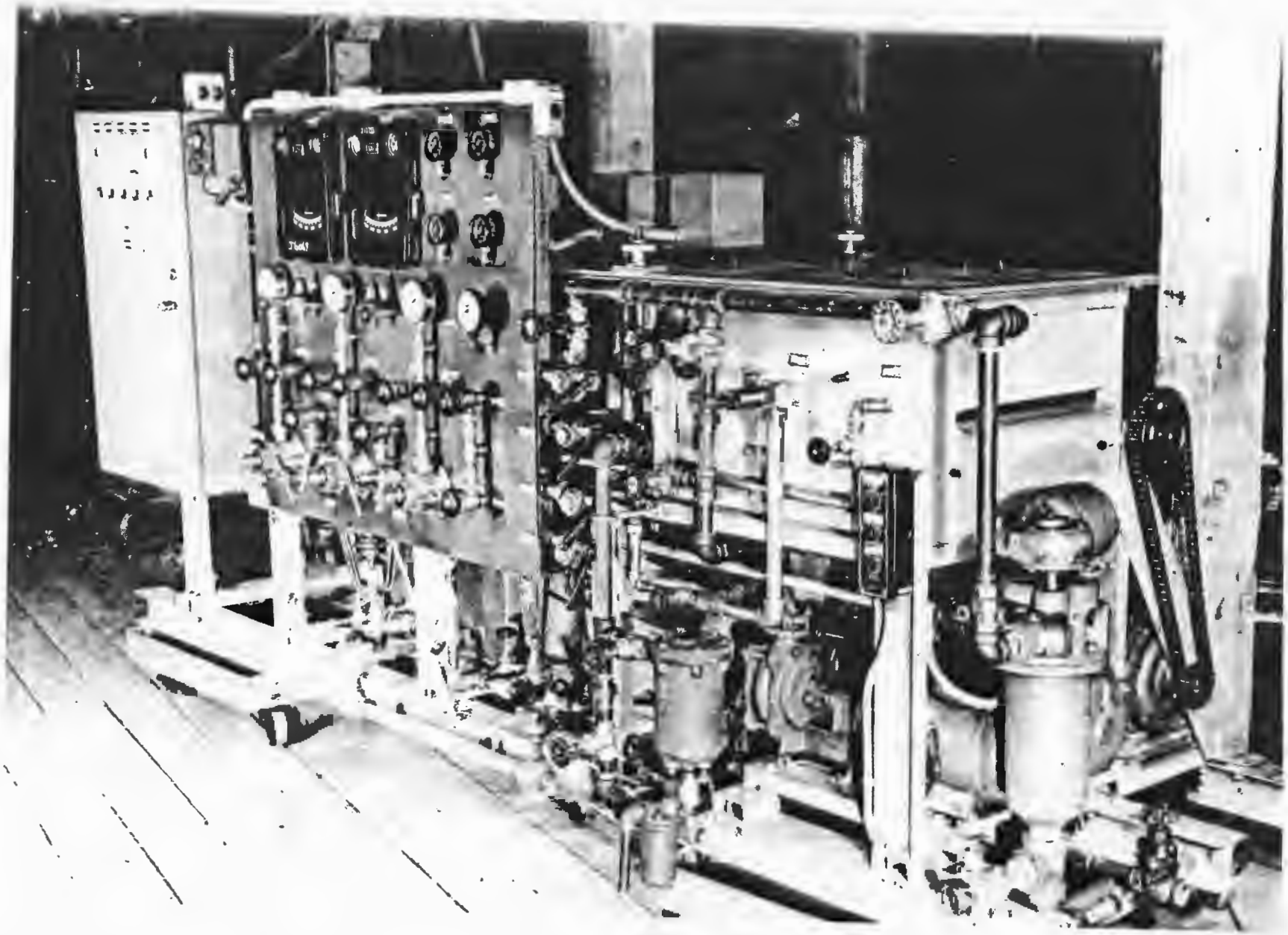
C2 Interior View of Hydrogenation Furnace with a Reel of Barrier Material in place.

[redacted]

[redacted]

C3 [redacted] DELETED [redacted] DOE b(3)

[redacted]



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C4

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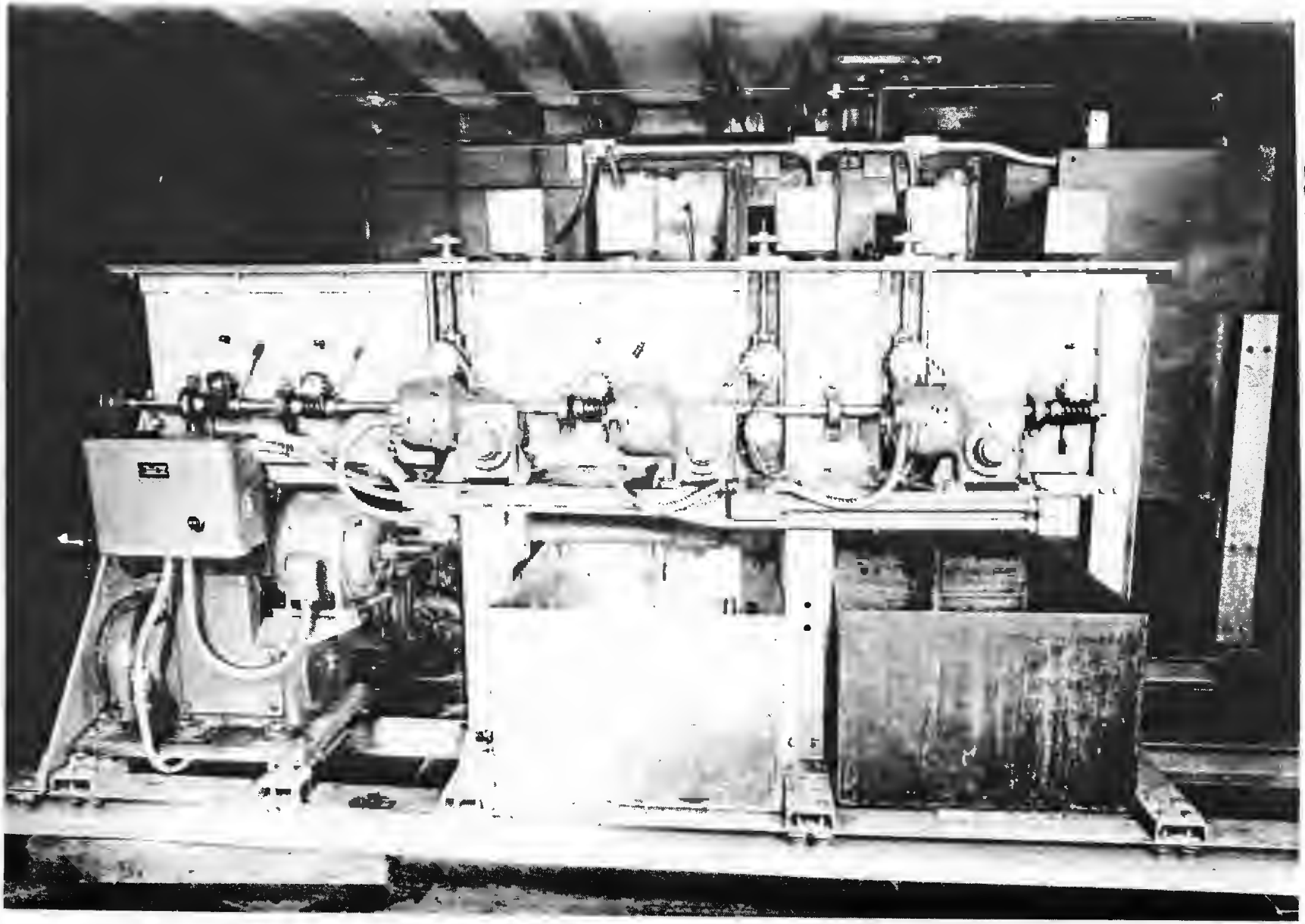
b(3)

[redacted]



[redacted]

[redacted]

C5

DELETED

DOE
b(3)

[redacted]

[redacted]

[redacted]

DELETED

[redacted]

DOE
b(3)

[redacted]

[redacted]

06

DELETED

[redacted]

DOE
b(3)

[redacted]

[redacted]

[redacted]

07

DOE
b(3)

[redacted]

[redacted]

DELETED

DOE
b(3)

[redacted]

[redacted]

[redacted]

DELETED

DOE
b(3)

[redacted]

[redacted]

[redacted]

DELETED

DOE
b(3)

[redacted]

C9

DELETED

DOE b(3)

[redacted]

[redacted]

DELETED

[redacted]

DOE
b(3)

[redacted]

310

DOE b(3)

DELETED

[redacted]

[redacted]

DELETED

DOE
b(3)

[redacted]

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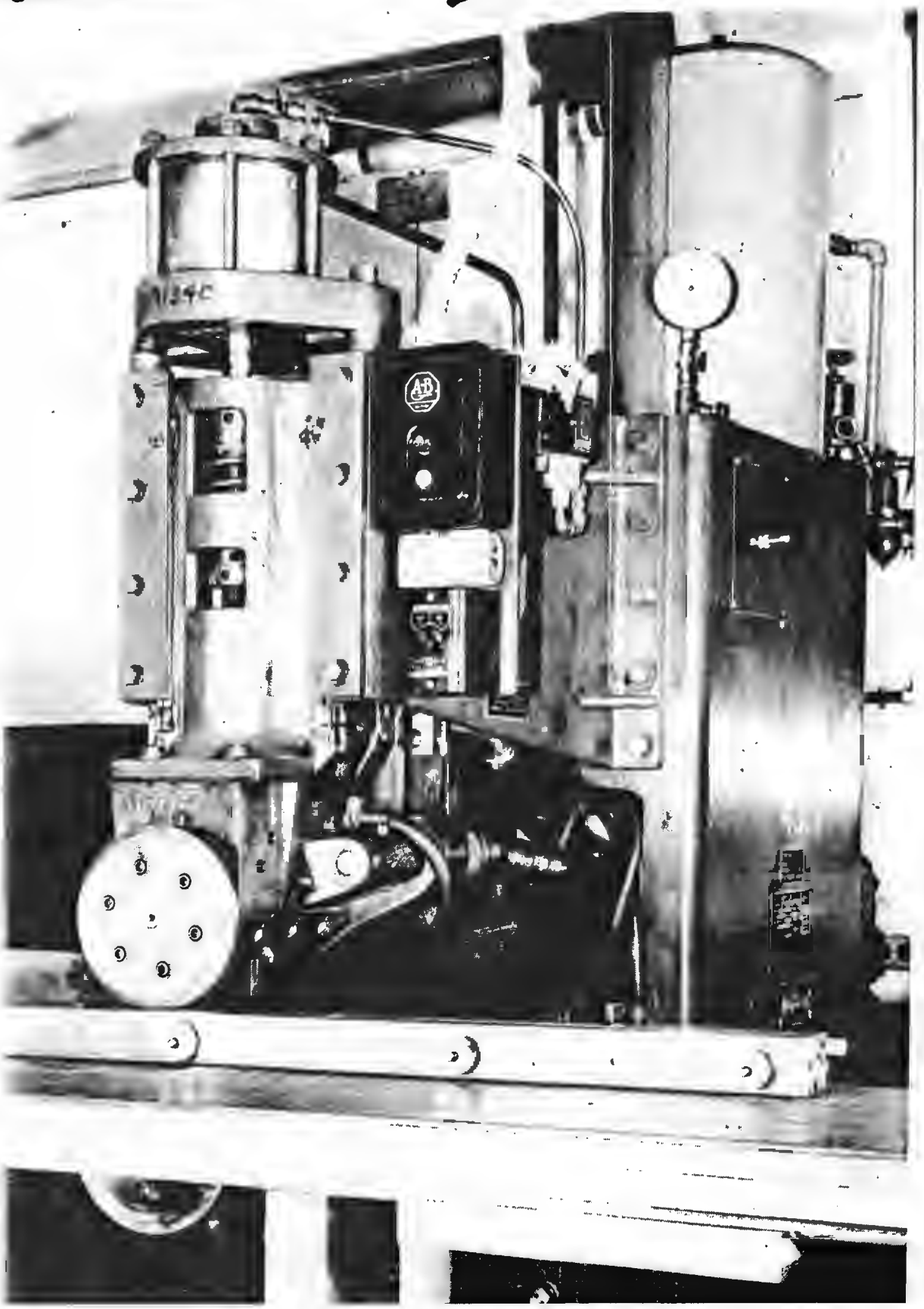
C11 DELETED

DOE 6(3)

[redacted]

[redacted]SECRET



[redacted]

012

DELETED

DOE b(3)

[redacted]

[redacted]

DELETED

DOE
b(3)

[redacted]

[redacted]

013

DELETED

DOD
b(3)

[redacted]

[redacted]

DOE
b(3

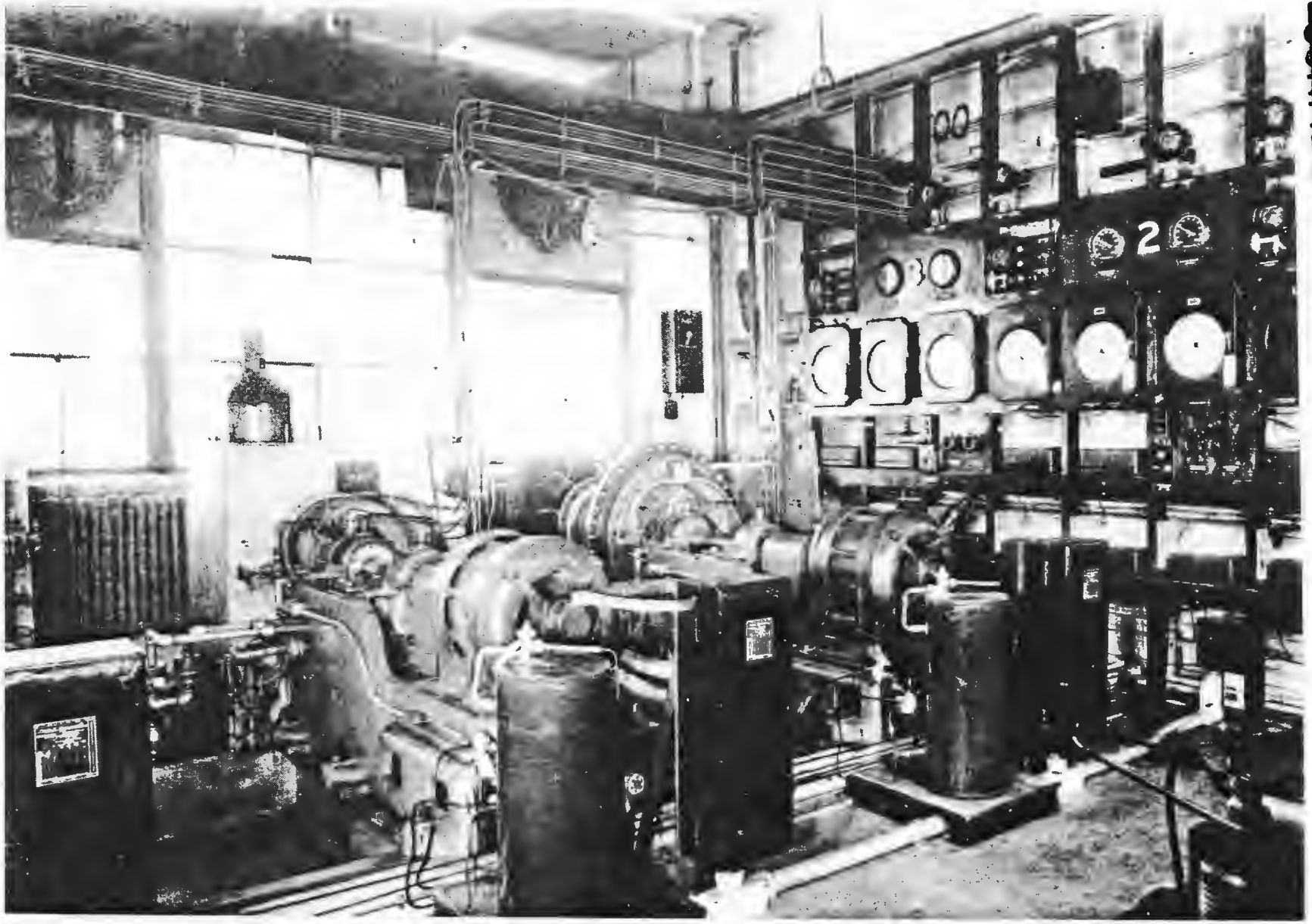
DELETED

[redacted]

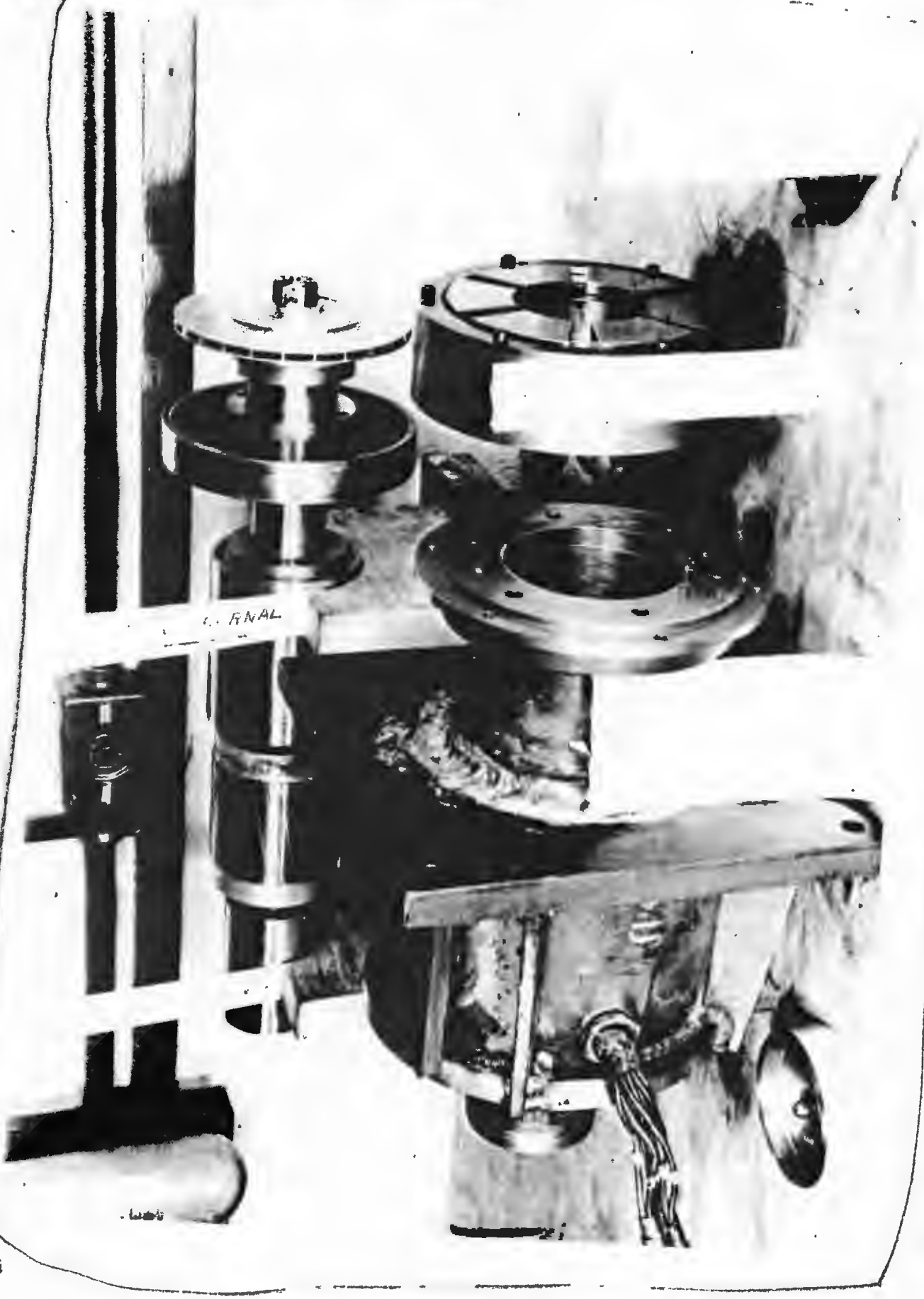
DELETED

DCG
b(3)

[redacted]


2

C)5 Gas Bearing Blower. This is the first gas bearing model. It was constructed at the Pupin Physics Laboratories of Columbia University.



DOE
b(3)

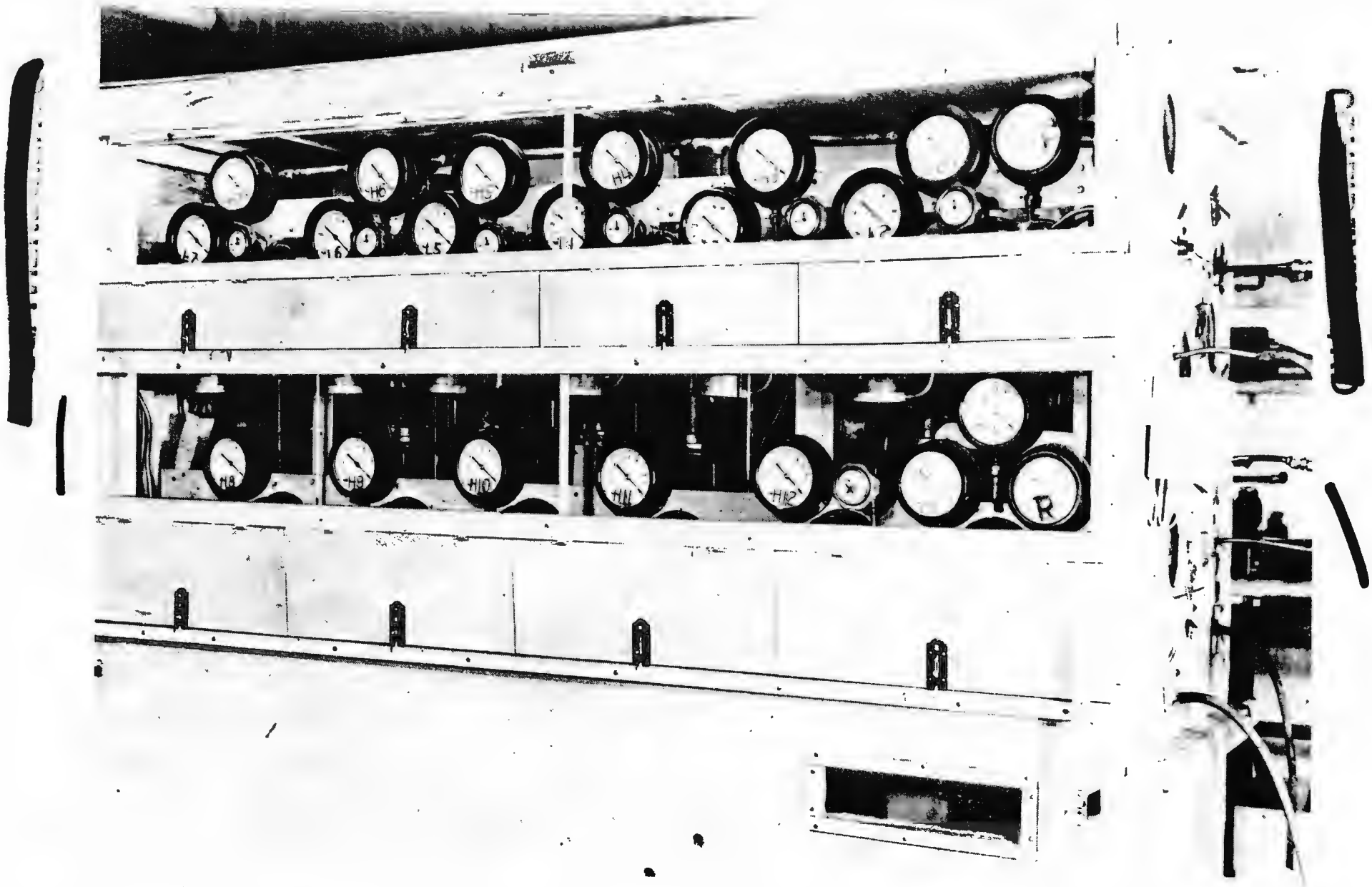
[redacted]

C[redacted]

C18 Westinghouse Model CSV Gas Bearing Blower. The auxiliary apparatus is being used to make life test studies of blower performance with process gas.

[redacted]

C17 Front View of Pilot Plant No. 1 (Code Name: Gertrude).

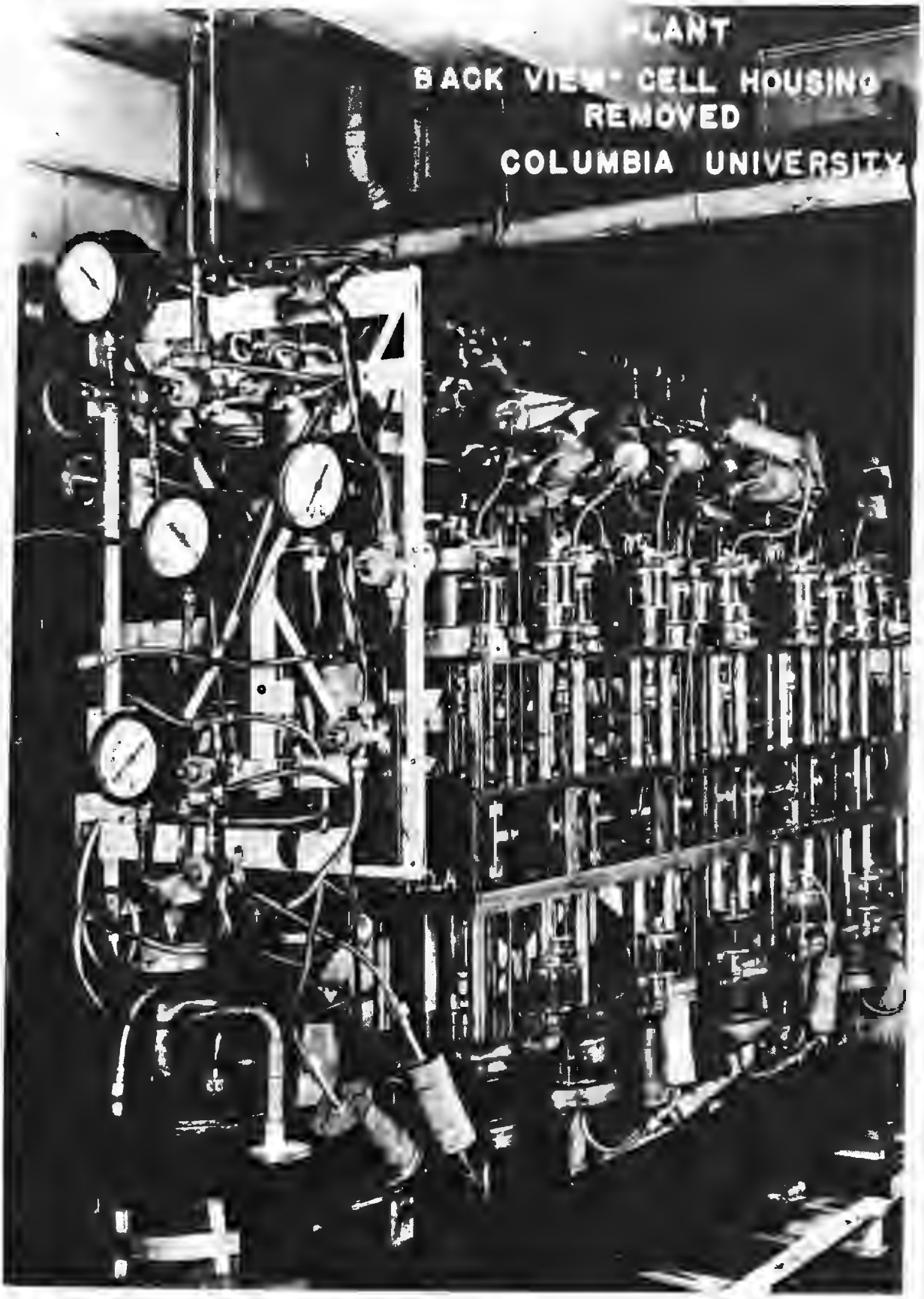

H6
H5
H4
H8
H9
H10
H11
H12
R

[redacted]

C18 Rear View of Pilot Plant No. 1.

[redacted]

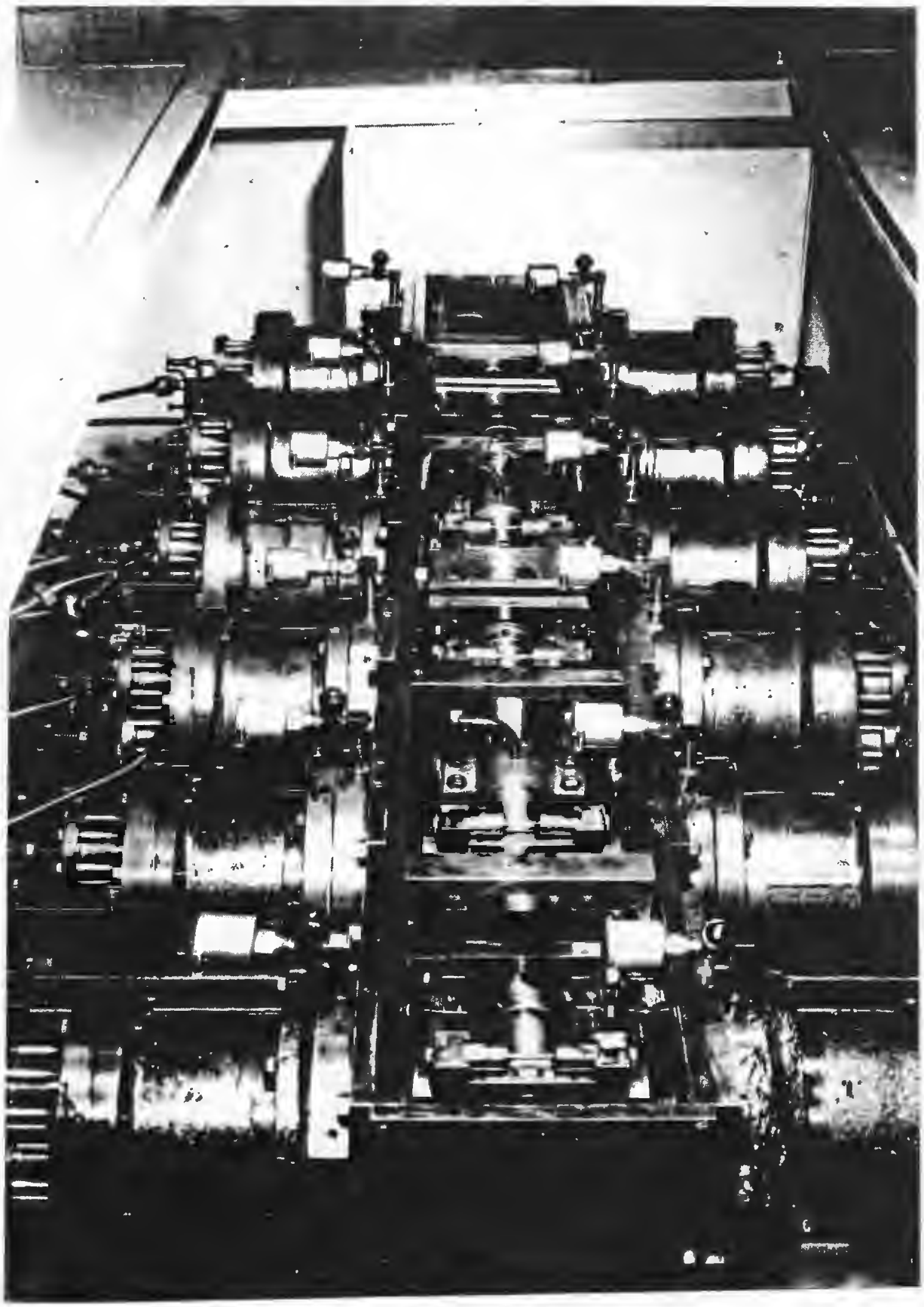
[redacted]


-LANT
BACK VIEW - CELL HOUSING
REMOVED
COLUMBIA UNIVERSITY

C19 Pilot Plant No. 1, showing a front view of the Twelve-Stage Cascade as first assembled in the Pupin Physics Laboratories of Columbia University. The diffusers, pressure indicators, piping, and valves are shown.

L6
L5

C20 Pilot Plant No. 1, showing a rear view of the original Twelve-Stage Cascade with Type B Pumps mounted as a Common Crankshaft.



C[redacted]

C21 Rear view of Pilot Plant No. 2, showing three Type W Pumps.

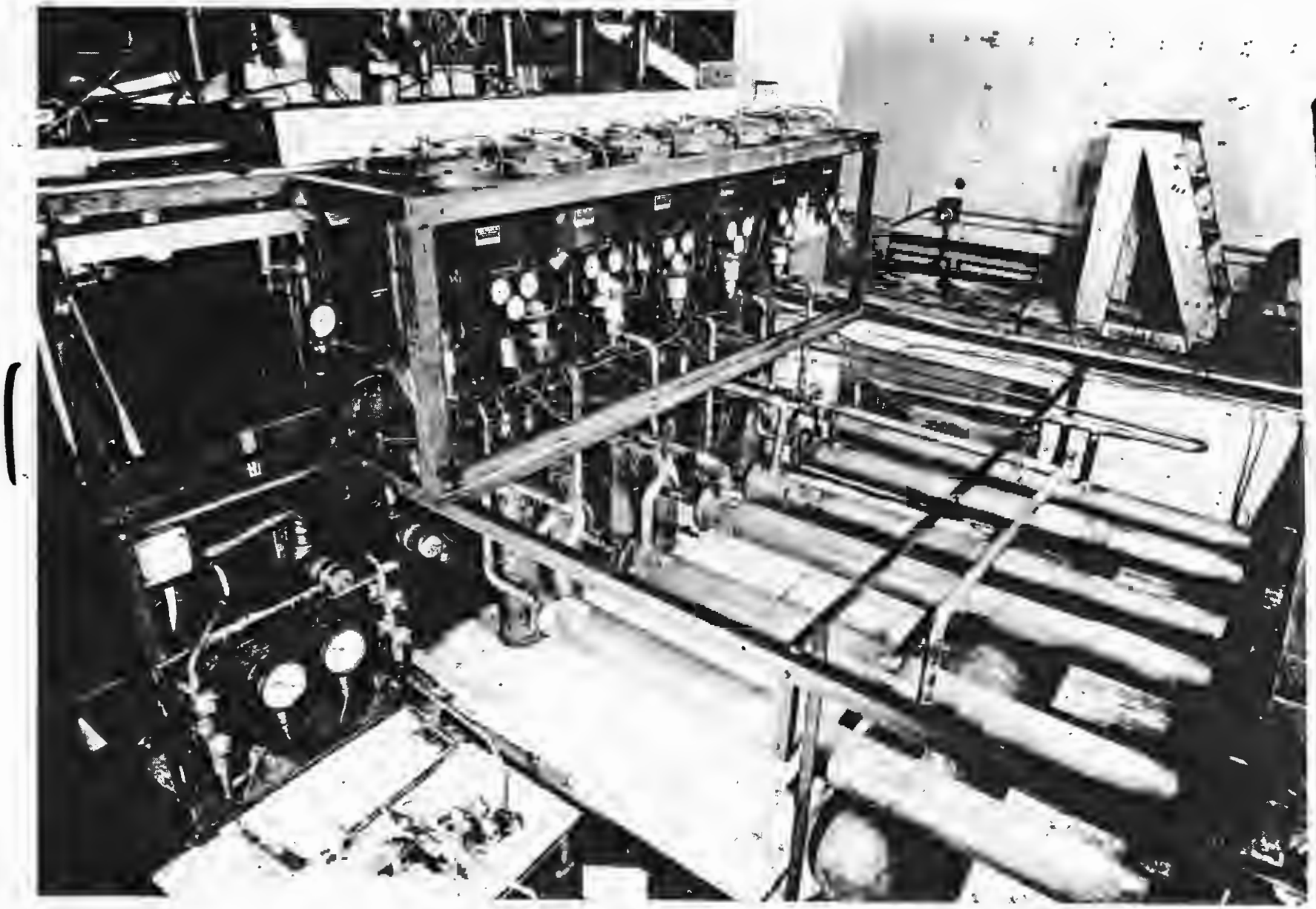
[redacted]

[redacted]

C22 Interior View of Pilot Plant No. 2, showing Diffusers and Pressure Transmitters. During operation, the diffusers are housed in a constant temperature chamber.

[redacted]

[redacted]

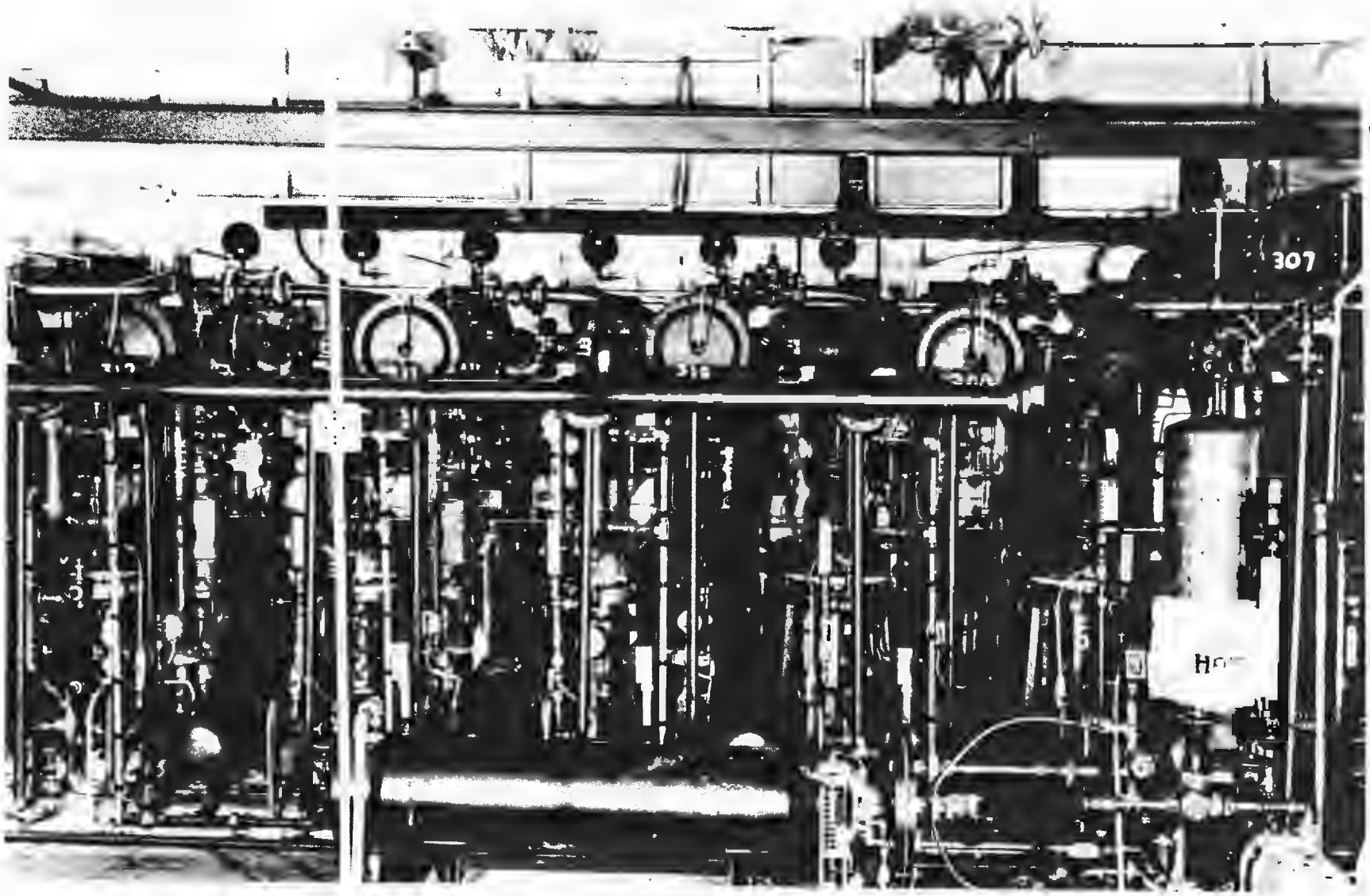


C23 Pilot Plant No. 3A, showing a view of the Main Instrument Panel.

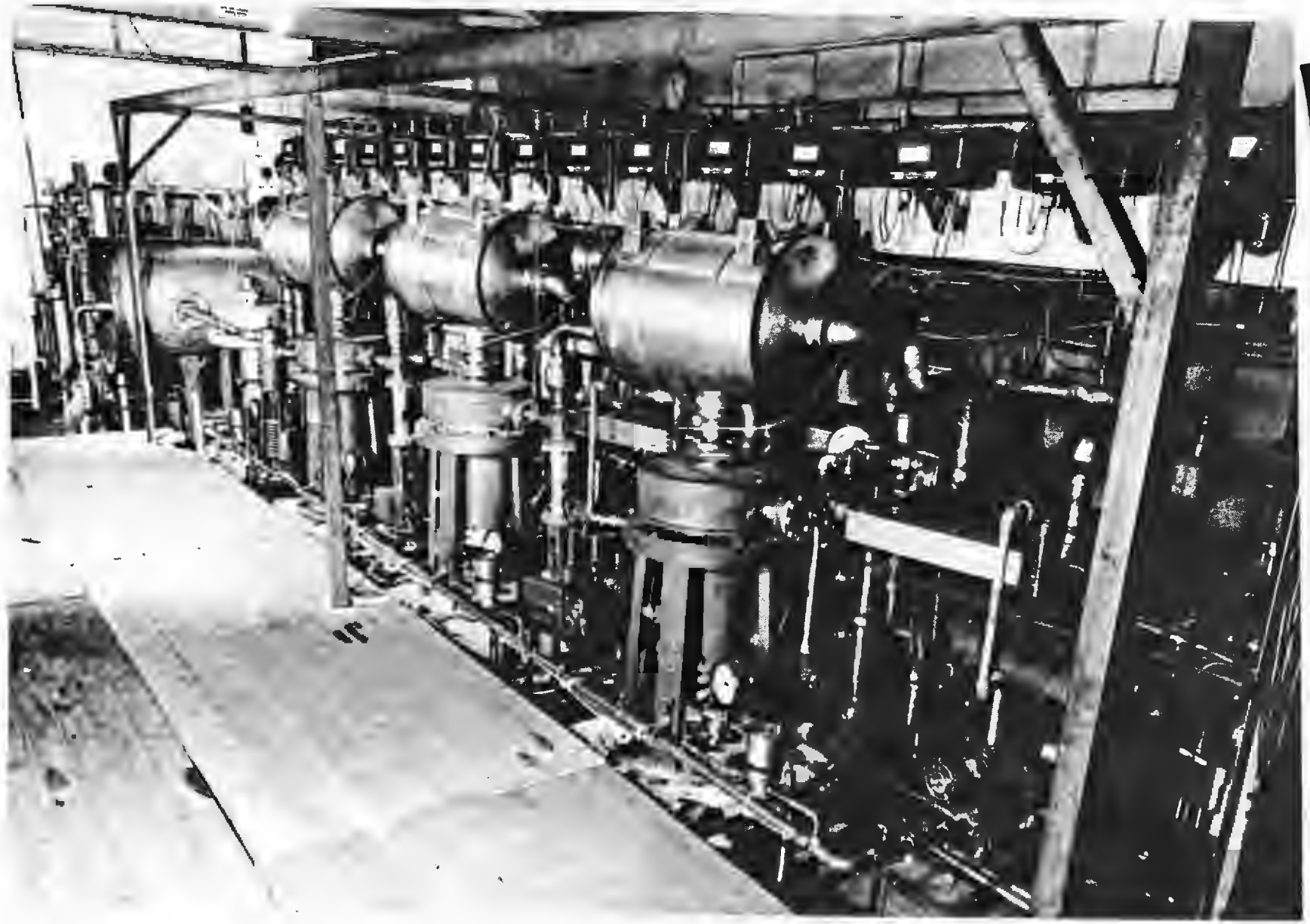
[redacted]

C24. Rear view of Pilot Plant No. 3A, showing the four Top Stages, and (in the foreground) the Motor Coolant Circulating System.

[redacted]


307

C25 Pilot Plant No. 3B, showing Stages 2, 4, and 6, Type CS-V Gas Bearing Blowers, Blower Repressuring System, Whitehead Diffusers, Surge Drum, and Heat Exchangers.



[redacted]

C26 Pilot Plant No. 3B, showing Stages 1, 3, and 5, Blowers, Diffusers, Control Instruments, and Sampling Manifolds.

[redacted]

[redacted]

JN4807

[redacted]

C27 View of Vacuum Engineering School, showing Students examining Electronic Equipment used in Leak Detecting Apparatus.

[redacted]

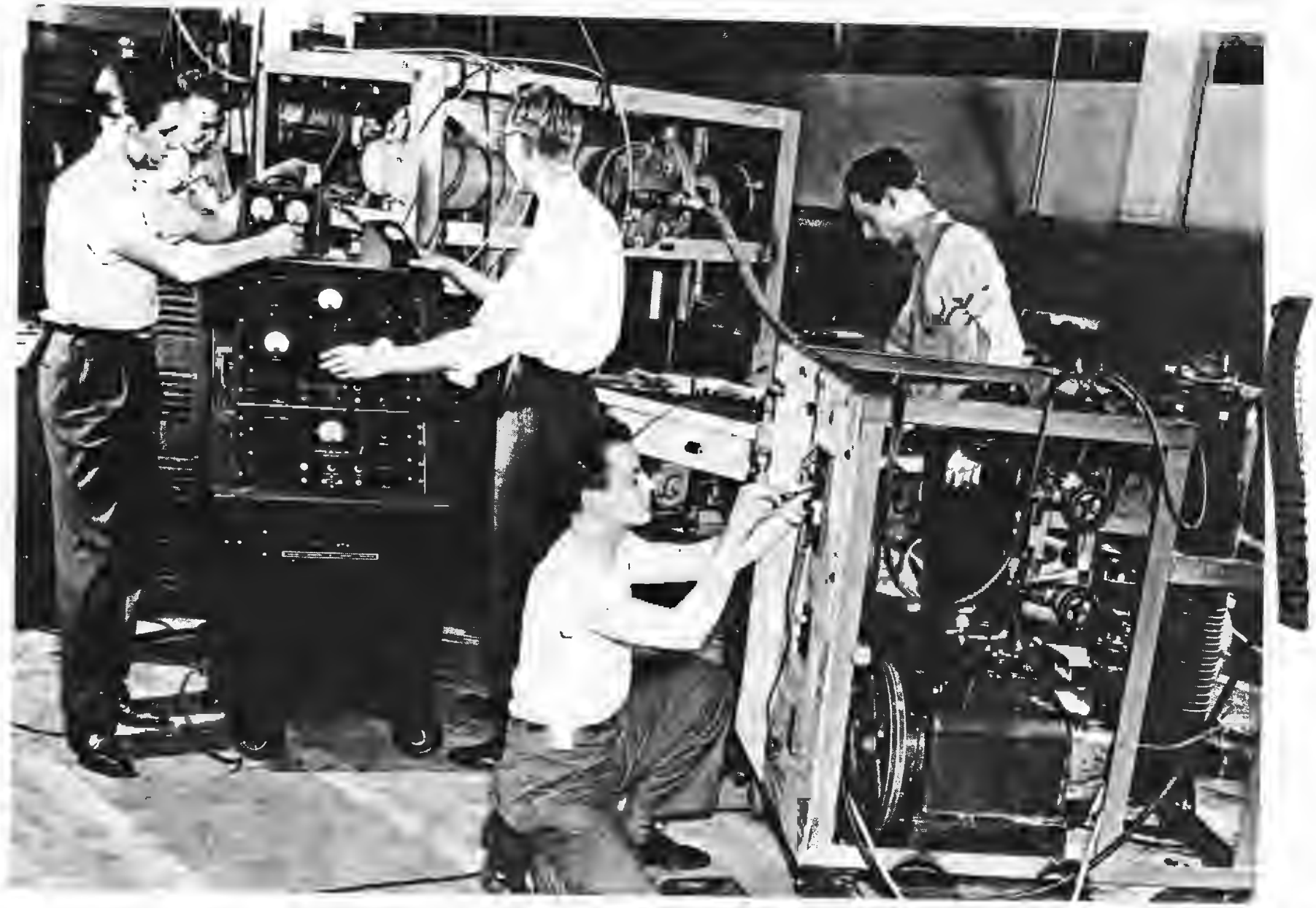
[redacted]

[redacted]

C28 Vacuum Engineering School, showing a Leak Detector and a Pumping Wagon being assembled.

[redacted]

[redacted]



[redacted]

C29 Vacuum Engineering School, showing the Mass Spectrometer Leak Detector.

[redacted]

MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 2 - RESEARCH

APPENDIX "D"

FILE AND LITERARY REFERENCES

No.	Reference
	(M.D.T.R. indicates Manhattan District Technical Report File)
1.	Naturwiss, Vol. 27, p. 11, 89 (1939) - O. Hahn and F. Strassmann.
2.	Physical Review, Vol. 55, p. 511 (1939) - H. L. Anderson, E. T. Booth, J. R. Dunning, E. Fermi, G. N. Glasoe, F. G. Slack.
3.	Physical Review, Vol. 57, p. 546 (1940) - A. O. Nier, E. T. Booth, J. R. Dunning, and A. von Grosse.
4.	Physical Review, Vol. 56, p. 426, 1065 (1939) - N. Bohr, and J. A. Wheeler.
5.	Physical Review, Vol. 57, p. 748 (1940) - A. O. Nier, E. T. Booth, J. R. Dunning, and A. von Grosse.
6.	Physical Review, Vol. 57, p. 749 (1940) - K. H. Kingdon, H. C. Pollock, E. T. Booth, and J. R. Dunning.
7.	Total Areas, Pumping Speeds, and Stages for Diffusion Apparatus - Karl Cohen, October 1941. M.D.T.R. File No. A-96.
8.	Contract W-7405-eng-23, with The M. W. Kellogg Company, and The Kellex Corporation. Manhattan District Classified Contract Files.
9.	Contract OEMsr-412, with the Trustees of Columbia University. Superseded by Contract W-7405-eng-50. Manhattan District Classified Contract Files. (See App. A)
10.	Contract OEMsr-1125, with Western Electric Company (Bell Telephone Laboratories). Superseded by contract W-7405-eng-142. Manhattan District Classified Contract Files. (See App. A)

[redacted]

No.	Reference
11.	Contract W-7405-eng-98, with Princeton University. Manhattan District Classified Contract Files. (See App. A)
12.	The Kellex Corporation. The Diffusion Plant - First Progress Report. M.D.T.R. File No. A-825.
13.	T. A. Data Sheets, Section X. M.D.T.R. File No. LRC-64.
14.	Report on Subjects Discussed with British Representatives - Karl Cohen - 16-19 September 1943. M.D.T.R. File No. A-1211.
15.	On the Stability and Control of Diffusion Plants. Part 1. Concepts and Methods - Irving Kaplan and Karl Cohen - 5 April 1943; Part 2. Further Development and Application of the Variational Analysis - Karl Cohen, Irving Kaplan, and Harris Mayer - 7 January 1944; Part 3. Hydrodynamic Behavior and Criteria for Stability - Harris Mayer - 7 October 1944. M.D.T.R. File No. A-592.
16.	A Program of Experiments on the Hydrodynamic Behavior of the 54-Stage Pilot Plant (Building K-305-2X). Irving Kaplan, Edward M. Carson, and William A. Mierenberg - 15 January 1945. M.D.T.R. File No. A-2186.
17.	The Status of Barrier Development - The Kellex Corporation. J. F. Hegerton, Editor - 1 September 1945. New York Area Classified Files. File No. NY 400.112 (Barrier).
18.	
	DELETED
19.	
20.	
21.	Subcontract No. 1 under contract W-7405-eng-149 with the Houdaille-Hershey Corporation. Manhattan District Classified Contract Files.

DOE b(3)

[redacted]

[redacted]

No.	Reference
21a.	Subcontract No. 2 under contract W-7405-eng-149 with the Houdaille-Hershey Corporation. Manhattan District Classified Contract Files.
22.	Contract W-7405-eng-55 with the Houdaille-Hershey Corporation for research, development and pilot plant production of "A" Barrier. This was superseded by contract W-7405-eng-149 for procurement, design, installation of equipment and large scale production of barrier tubes. Manhattan District Classified Contract Files.
23.	Report on "A" Barrier - Edward Mack, Jr. - 15 June 1946. M.D.T.R. File No. A-4117.
24.	Minutes of Meeting held 16 January 1944 at Decatur, Illinois - Forwarded by Captain J. H. Brannan - File No. M-337 General - Case No. 3501.
25.	DELETED DOE b(3)
26.	BAM Powder Production - M. A. Coler et al. - 16 February 1945. M.D.T.R. File No. M-2213.
27.	The Pumping Problems in U-235 Diffusion Separation Plants - H. A. Boorse - 16 December 1941. M.D.T.R. File No. A-66.
28.	Oil-Free Sealed Pump for Corrosive Gases - E. T. Booth and Hugh C. Paxton - 6 February 1943. M.D.T.R. File No. A-115.
29.	W Pump Design - D. C. Sargeant - 9 November 1944. M.D.T.R. File No. M-1491.
30.	Pneumatically Operated Metal Diaphragm Pump - E. T. Booth, H. C. Paxton, and D. B. Cook - 27 July 1943. M.D.T.R. File No. A-209.
31.	Diffusion Separation Plants - J. R. Dunning - 15 February 1943. M.D.T.R. File No. A-536.
32.	DELETED DOE b(3)
33.	

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No.	Reference
34.	DELETED
35.	
36.	K-25 Operating Manual, Vol. XIV Process Pumps - R. L. Parrish.
37.	Life Test on Gas Bearing in Process Gas - H. A. Boorse, G. F. Booker, and J. R. Menke - 29 September 1943. M.D.T.R. File No. A-1207.
38.	Preliminary Report on Gas Bearings - H. A. Boorse, G. F. Booker and J. R. Menke - 15 May 1943. M.D.T.R. File No. A-1230.
39.	Test Report on Westinghouse Gas Bearing Centrifugal Compressor - H. A. Boorse et al. - 19 May 1944. M.D.T.R. File No. A-1278. Test of the General Electric Gas Bearing Blower - G. F. Booker et al. - 15 August 1944. M.D.T.R. File No. A-[illegible]12.
40.	Contract W-7415-eng-61 with Westinghouse Electric and Manufacturing Company for gas bearing blowers and motors. Manhattan District Classified Contract Files.
41.	Experimental Separation of Uranium Isotopes by Diffusion - E. T. Booth, H. C. Paxton, and C. B. Slade - 17 February 1942. M.D.T.R. File No. A-105.
42.	Process Gas Separation Tests - R. B. Pontius et al. - 18 November 1943. M.D.T.R. File No. A-1219.
43.	High-Cut Barrier Testing - L. Davidson, W. A. Nierenberg, and C. Williams - 30 March 1944. M.D.T.R. File No. A-1259.

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No.	Reference
44.	Barrier Tests on No. 1 Pilot Plant - C. B. Slade and D. B. Cook. 13 November 1944. M.D.T.R. File No. A-2162.
45.	The No. 2 Pilot Plant - S. Cromer et al. - 18 October 1944. M.D.T.R. File No. A-2140.
46.	Completion Report on Pilot Plant 8A - Clarke Williams et al. 20 November 1944. M.D.T.R. File No. A-2152.
47.	Hydrodynamic Behavior of the No. 8 Pilot Plant - Irving Kaplan. 6 October 1944. M.D.T.R. File No. A-2137.
48.	Operation of Blower - H. C. Paxton and S. Visner - 28 July 1944. M.D.T.R. File No. A-1120.
49.	Porosity and Life-Plugging Test on Tubular Diffusers - S. Visner et al. - 20 October 1944. M.D.T.R. File No. 2144.
50.	Electronic Pressure Transmitter and Self Balancing Relay - S. Cromer - 18 April 1944. M.D.T.R. File No. A-1286.
51.	Specific Heat of Uranium Hexafluoride - E. T. Booth et al. 27 December 1941. M.D.T.R. File No. A-67.
52.	Flowmeter for Uranium Hexafluoride - E. T. Booth et al. 5 January 1942. M.D.T.R. File No. A-68.
53.	Thermal Flowmeters - C. D. Swartz - 15 January 1945. M.D.T.R. File No. A-5219.
54.	Report on Analytical Service - J. R. Dunning - 5 October 1944. M.D.T.R. File No. M-1173.
55.	Testing Isotopic Concentration of Uranium - J. R. Dunning, E. T. Booth, and A. von Grosse - July 1940. M.D.T.R. File No. A-62.
56.	The Counting Method of Isotopic Analysis of Uranium - Part 1 - D. E. Hull - 18 January 1944; Part 2 - Preparation of Films - Benjamin Cohen and D. E. Hull - 28 August 1944. M.D.T.R. File No. A-1235.
57.	Report on SAM Vacuum Engineering School - C. B. Ellis - 24 July 1944. M.D.T.R. File No. A-2127.

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No.	Reference
58.	Status of Metallographic Investigations of Electronickel Barriers - C. E. Pellisier - 14 October 1943. M.D.T.R. File No. A-1210.
	Electron Microscope Study of Barrier Structure - L. T. Newman and W. C. Skinner. - 1 November 1944. M.D.T.R. File No. A-2152.
59.	Bibliography on the Physical Properties of Uranium Hexafluoride. Helen Johnston - 18 July 1944. M.D.T.R. File No. A-1297.
60.	Bibliography on the Chemistry of Uranium Hexafluoride - Helen Johnston - 29 July 1944. M.D.T.R. File No. A-2100.
61.	DELETED DOE b(3)
	Mechanical Testing of Barriers - C. Beck - 13 October 1943. M.D.T.R. File No. A-1253.
62.	Thermal and Electrical Properties of Barrier Material - A. R. Sayer et al. - 15 January 1945. M.D.T.R. File No. A-2200.
63.	DELETED DOE b(3)
64.	Report for 1-15 December 1944 - W. F. Libby - 29 December 1944. M.D.T.R. File No. M-1469.
65.	Standard System for Testing Diffusive Barriers - E. Briggs et Al. 17 August 1944. M.D.T.R. File No. A-2184.
66.	Review of Barrier Separation Theory - W. G. Pollard and A. J. de Bethune - 29 December 1944. M.D.T.R. File No. A-2194.
67.	General Electric Gas Analyzer - Mario Antonazzi - 29 December 1944. M.D.T.R. File No. A-2178.

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No.	Reference
68.	Rapid Separation Measurements on Full Length Tubes - Richard N. Bernstein - 27 October 1944. M.D.T.R. File No. A-2147.
69.	Standard Diffusive Measurements on Short Tubular Barriers - W. A. Schneider, R. Bernstein, and D. Trauger - 15 June 1944. M.D.T.R. File No. A-2187.
70.	Bibliography on the Corrosive Action of Uranium Hexafluoride, Fluorine, Hydrogen Fluoride, and Fluorocarbons - Helen Johnston - 15 September 1944. M.D.T.R. File No. A-2101.
71.	Fluorocarbon Oils - W. T. Miller - 5 January 1945. M.D.T.R. File No. A-2182.
72.	Tests on Crane Valves with KEL-10 Seats - S. Visner, F. L. Alexander, and C. R. Clark - 9 February 1945. M.D.T.R. File No. A-2222.
73.	Purchase Orders by SAM Laboratories under Contracts OEMsr-412
	and
74.	W-7405-eng-50 with Columbia University.
75.	Purchase Orders for Special Pressure Transmitters under contract OEMsr-412 and W-7405-eng-50.
76.	Contract W-7415-eng-40 with General Electric Company for furnishing Differential Pressure Panels and Transmitters. Manhattan District Classified Contract Files.
77.	Contract W-7418-eng-65 with General Electric Company for furnishing Mass Spectrometers and Leak Detectors. Manhattan District Classified Contract Files.
78.	Contract W-7405-eng-271 with General Electric Company for furnishing Recording Gas Analyzers. Manhattan District Classified Contract Files.
79.	Contract W-7418-eng-14 with Mayler Instrument Company for furnishing Process Plant Instruments. Manhattan District Classified Contract Files.
80.	Contract W-7418-eng-52 with Republic Flow Meter Company for furnishing Magnetically operated Control Valves. Manhattan District Classified Contract Files.

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No.	Reference
81.	Contract W-7407-eng-34 with Ford, Bacon, and Davis for the operation of the K-25 Conditioning Plant. Manhattan District Classified Contract Files.
82.	Contract W-7405-eng-26 with Carbide and Carbon Chemicals Corporation for the operation of the Diffusion Plant. Manhattan District Classified Contract Files.
83.	Contract W-7418-eng-18 with Crane Company for furnishing Special Process Valves. Manhattan District Classified Contract Files.
84.	Contract W-7405-eng-34 with Allis-Chalmers Company for A.E.M. services for procurement of equipment for a plant to manufacture centrifugal pumps for Process Plant. Manhattan District Classified Contract Files.
85.	Contract W-7405-eng-62 with Allis-Chalmers Company for design and development and manufacture of Pumps and Drivers for Pilot Plant. Manhattan District Classified Contract Files.
86.	Contract W-7405-eng-63 with Allis-Chalmers Company for furnishing Pumps and Drivers for Diffusion Plant. Manhattan District Classified Contract Files.
87.	Contract W-7423-eng-11 with Whitehead Metal Products Company for plate diffusers for purge system. Manhattan District Classified Contract Files.
88.	Contract W-7401-eng-14 with Linde Air Products Company for design and construction of a plant to produce nickel oxide. Manhattan District Classified Contract Files.
89.	DELETED DOE b(3)
90.	Contract W-7415-eng-35 with A. O. Smith Corporation for furnishing Process Gas Coolers. Manhattan District Classified Files.
91.	Report on Discussion of Contracts at Columbia. M.D.T.R. File No. A-3256.
92.	Minutes of "Meeting Held on October 16 in Room 776 on the S Stage" - C. R. Hinher (Kellex). - 20 October 1945, Kellex Files.

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No.	Reference
93.	Final Report on Contracts OEMsr-105, OEMsr-107, OEMsr-192, OEMsr-412, and Associated Subcontracts. H. C. Urey - 28 February 1944. Columbia Serial No. 100 UR-355. M.D.T.R. File No. A-1935.
94.	Barrier Specifications Book by The Kellex Corporation.
95.	SAM Report dated 14 May 1945, SAM #32288 (ACR-190) by Dr. G. M. Murphy, "Nomenclature of Barrier and Barrier Material."
96.	Preliminary Report under contract W-7401-eng-63 with California Institute of Technology. - Richard H. Badger - 20 September 1943. Columbia Serial No. 100 XR-2643. M.D.T.R. File No. A-796.
97.	DELETED
98.	E. Goldstein, Ber. Preuss. Akad. Wiss., Vol. 39, p. 691 (1886).
99.	W. Wien, Ann. d. Physik, Vol. 65, p. 440 (1898).
100.	J. J. Thomson, Phil. Mag., Vol. 15, p. 561 (1907).
101.	A. J. Dempster, Phys. Rev., Vol. 11, p. 316 (1918), Vol. 20, p. 631 (1922).
102.	F. W. Aston, Phil. Mag., Vol. 38, p. 707 (1919), Vol. 39, p. 449, 611 (1920).
103.	F. W. Aston "Mass Spectra and Isotopes", Longmans, Green, and Company (1933).

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MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 2 - RESEARCH

APPENDIX "E"

DOCUMENTARY EXHIBITS

No.	Title
1.	Minutes of Meeting held 10 January 1944 at Decatur, Illinois.

[redacted]

ADDRESS REPLY TO
THE AREA ENGINEER

WAR DEPARTMENT
MANHATTAN ENGINEER DIST.....
DECATUR AREA
P. O. BOX 140
DECATUR 60 ILLINOIS

IN REPLY REFER TO EIDM DEC-1

[redacted]

Minutes of Meeting held 16 January 1944 at Decatur, Ill.

Those present were:

Army - Brigadier General L. R. Groves
Lt. Col. James C. Stowers
Major A. Tammaro
Captain John H. Bramman
Lt. Homer D. Walker

Houdaille-Hershey Corporation -
Mr. C. G. Getler
Mr. Don S. Devor
Mr. Sanford Brown
Mr. Paul H. Davis
Mr. J. K. MacLennan
Mr. W. L. Pinner
Mr. R. C. Smith
Dr. A. K. Graham

Kellex Corporation -
Mr. P. C. Keith
Mr. A. L. Baker
Mr. P. B. Gordon

Columbia University -
Dr. Harold C. Urey

Union Carbide & Carbon Company -
Dr. Merrill
Dr. George Felbeck

1. Investigational by H.H.
Major K (not to be interfered w/by the minor)
Minor A modified in any way H.H. desires

2. Construction
Build for K.

3. Plan for K. process.

K investigational in N.Y. in present org. headed by Taylor. H.H. to furnish everyone needed to fill in that organization.

Const. and process changes to be worked out by Kellex w/H.H. advice.

Stop production of all unnecessary equipment at once.

HH. to continue in present position.

UCC to take overall supervisory position, will tie everything together from beginning to end. Ultimate veto power over differences of opinion within overall directives of Kellex as to required specs and deliveries. To be worked out in detail by UCC and Kellex. UCC will secure powders, blend, manufacture sheet and furnish to H.H.

Kellex to coord. product w/ Chrysler and site and other outside agencies.

Stowers to be responsible for delivery priorities and any failures on his part to be reported at once to me or Mrs. O'Leary by phone.

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MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 2 - RESEARCH

APPENDIX "F"

GLOSSARY

Term	Definition
Alnico	- a highly magnetic metallic alloy containing 24-36 per cent nickel, 9-15 per cent aluminum, and 5-10 per cent cobalt.
C-2144	- a highly fluorinated lubricating oil suitable for use in contact with fluorine or uranium hexafluoride (Book VII).
Chain reaction	- a reaction which proceeds in such manner that minute, fundamental, component entities react with one another in such a way that one or more of the products resulting from each fundamental reaction acts as a reagent to initiate an identical reaction in adjacent similar material. If the products resulting from a specified number of fundamental reactions cause the initiation of an equal (or greater) number of secondary reactions, the chain reaction is said to be self-sustaining or (multiplying).
Kovar	- a metallic alloy used in forming metal to glass joints. A typical analysis would be 29 per cent nickel, 17 per cent cobalt, 0.5 per cent manganese, and a trace of iron.
	DELETED Dec b(3)
MFP-10	- a highly fluorinated plastic material suitable for use in contact with fluorine or uranium hexafluoride (Book VII).
Nuclear fission	- the process in which the nucleus of an atom is split into several parts which are of the same order of magnitude, as distinguished from a process in which a small part of the nucleus, of weight equal to only a small fraction of the total nucleus, is split off.

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Term	Definition
Poly TFE	- a special fluorinated plastic resistant to uranium hexafluoride and fluorine, and consisting of a polymer of tetrafluoroethylene (Book VII).
Radioactive decay constant	- a numerical quantity used to express the intensity of radioactivity of an element. It is mathematically defined as the ratio of the number of atoms decaying per unit time, at a given instant, to the number of atoms present at that instant.
SAE 52-100 steel	- one of a large number of steels specified for a particular use by the Society of Automotive Engineers.
Sylphon	- trade name for a particular type of corrugated metal bellows.

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Vycor glass - a commercial glass of high silica content.

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MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 2 - RESEARCH

APPENDIX "G"

KEY PERSONNEL

No.	Title
1.	Key Personnel, Columbia Area.
2.	Key Personnel, SAM Laboratories.
3.	Key Personnel, Bell Telephone Laboratories
4.	Key Personnel, Princeton University
5.	Key Personnel, Kellex Corporation (Research only)
6.	Key Personnel, Interchemical Corporation
7.	Key Personnel, California Institute of Technology

[redacted]

Hough, Major B. K. Jr. - Area Engineer from March 1943 to January 1944; administration of research contracts under the jurisdiction of the Columbia Area.

Browne, Captain S. H. - Technical Advisor to the Area Engineer on matters pertaining to scientific research and development from June 1943 to February 1944.

Gambs, Captain C. C. - Executive Officer from May 1944 to July 1945; assisted in the administration of contracts, and the supervision of Area Office activities.

Grotian, Captain L. L. - Executive Officer from June 1942 to January 1944. Area Engineer from January 1944 to 1 July 1946; responsible for administration of contracts under the jurisdiction of the Columbia Area.

Hicks, Captain K. J. - Executive Officer; assisted in the administration of contracts, and the supervision of Area Office activities.

Luke, Captain C. D. - Technical Advisor to the Area Engineer on matters pertaining to scientific research and development from February 1944 to November 1944.

Rosenblum, Captain C. A. - Assistant to the Area Engineer, New York Area; research chemist directing Kellex and SAM laboratory group on barrier development and quality control problems.

Mawhinney, Lt. R. J. (U.S.N.R.) - Assigned for duty to the Patent Advisor, Manhattan District.

Oberholtzer, 1st Lt. A. V. - Assigned for duty to the Patent Advisor, Manhattan District.

Pond, 1st Lt. D. C. - Assigned for duty to the Patent Advisor, Manhattan District.

Walsh, 1st Lt. H. R. - Assigned in September 1945 by the Manhattan Intelligence and Security Division to Columbia Area, directing Area Intelligence and Security Section.

Allan, 2nd Lt. G. S. - Assigned by the Manhattan District Intelligence and Security Division to Columbia Area, directing Area Intelligence and Security Section, from January 1944 to June 1945.

Callender, M/Sgt. J. H. - Special Assistant to the Area Engineer; Project Architect; prepared special reports for the Area Engineer; controlled issuance of special process materials to contractors.

[redacted]

Dziurzynski, M/Sgt. J. L. - Directed the Property, Procurement and Equipment Control Section; maintained property records for the Area Office and for contractors.

Fischer, D. - Supervised administrative sections of the Area Office; Chief Project Auditor performing final audit on contractors' vouchers.

KEY PERSONNEL, SAM LABORATORIES

Adler, Dr. Edward - DELETED) DOE 6(3

Beck, Dr. Clifford K. - Supervised research on methods for the mechanical testing of barriers; January 1943 - December 1944.

Blanchard, Dr. Edward R. - DELETED) DOE 6(3)

Booker, Dr. Gilbert F. - Conducted research on gas bearing blowers and their fundamental behavior and design.

Booth, Dr. Eugene T. - Directed the work of all physics research groups concerned with studies of methods for testing separating efficiency and physical properties of barriers, as well as assay methods such as mass spectrometers, counters, fission analysis, etc.

Brown, Dr. Earl H. - Conducted research on the composition of furnace gases and the effect of furnace atmosphere on barrier ductility; February 1943 - June 1944.

Brown, Dr. Franklin B. - Directed the work of all applied chemistry and chemical engineering groups concerned with barrier development.

Brown, Dr. Henry - DELETED) DOE 6(3)

Cady, Dr. George H. - Supervised research on the synthesis of fluorocarbons; January 1942- April 1943.

Callihan, Dr. A. Dixon - Conducted research on tests and measurements of the flow of uranium hexafluoride and inert gases through barriers. Performed early experiments on high temperature fluorination of barriers to increase corrosion resistance.

Cines, Dr. Martin R. - Conducted research on dust plugging and surface areas of barriers; January 1944 - January 1945.

Clark, Dr. Charles R. - Supervised research on plant conditioning processes, conditioning equipment and systems; design and life test studies on valves; experimental operation of pilot plants.

Coe, Dr. James R. Jr. - Conducted research on the use of fluorocarbon oils as lubricant in the presence of uranium hexafluoride; December 1942 - August 1943.

Cohen, Dr. Karl P. - Directed the fundamental theoretical and mathematical studies of plant design and operation; July 1940 - April 1944.

Cook, Dr. Graham - Assistant the Director in directing and coordinating all research and development studies with special emphasis upon major administrative problems.

Craig, Louis B. - DELETED

DOE b(3)

Creighton, Dr. H. Jermain - Supervised all patent work and acted as special consultant and liaison officer between SAM and Decatur on DA barrier production.

Crist, Dr. Ray H. - Directed and coordinated all research and development studies conducted for the Manhattan District at the Carbide and Carbon Chemicals Corporation, SAM Laboratories.

Cromer, Sylvan - Supervised the construction and operation of pilot plants for testing barrier performance in isotope separation; February 1943 - November 1944.

Currie, Dr. Lauchlin M. - Assisted and coordinated all research and development, with special attention to administrative duties; Associate Director of SAM Laboratories, January 1944 - February 1945; Consultant from latter date.

Davis, Dr. Hugh G. - DELETED

DOE b(3)

Day, Dr. Thomas G. - Supervised research and development on flow properties of barriers, microscopic and heat treatment studies; laboratory services for the barrier production group.

DeVries, Dr. Thomas - Conducted research on laboratory techniques involved in corrosion studies and investigated the behavior of rubber when exposed to corrosive gases; December 1943 - June 1944.

DeWitt, Dr. Thomas W. - Conducted research on absorption and surface areas of barriers; January 1944 - December 1944.

Donelian, Khatchik O. - Conducted researches on the development of diaphragm motors, starting and stopping of gas bearing blowers, new types of blowers and blower bearings.

Dunning, Dr. John R. - Directed all research and development on mechanical engineering problems, pilot plants, process operations and isotopic methods of analysis; July 1940 - December 1945. Directed all research on the diffusion project at Columbia University from July 1940 - December 1941.

Elgin, Dr. Joseph C. - Directed research and development of DA barrier, including pilot plant production; March 1944 - January 1945; consultant since latter date.

[redacted]RD

Ellis, Dr. Cecil S. - Conducted research and development of vacuum testing; directed school for the training of vacuum engineers; February 1943 - July 1944.

Emmett, Dr. Paul H. - Directed all chemical research dealing with consumption, plugging and stabilization of barriers; with the corrosion materials and with the development of fluorocarbons; August 1943 - November 1944; consultant since latter date.

Faust, Dr. Charles M. - DELETED

DOE b(3)

Finlayson, D. Kenneth - Assisted in the direction of research and development of A barrier; planned and organized laboratory and pilot plants for this purpose; March 1943 - January 1944.

Fowler, Dr. Robert D. - Supervised studies of plant conditioning to the corrosive action of gases; November 1945 - July 1944.

Freed, Dr. Simon - Conducted research on X-ray diffraction and electron diffraction studies of surfaces of materials of plant construction.

Gilbertson, Dr. Lyle I. - DELETED

DOE b(3)

Gillies, Daniel A. -

Gottschall, Herbert A. - Supervised operation of the A barrier pilot plant; July 1943 - January 1945.

Grosse, Dr. Aristid von - Supervised research on fluorocarbons, on the inorganic chemistry of uranium compounds and on their physical properties; July 1940 - December 1943.

Haendler, Dr. Helmuth M. - Conducted research on organic and other contaminating materials in plant, and special studies on stabilization; developed control methods for barrier manufacture.

Hagg, Arthur C. - Conducted research on mechanical problems dealing with the gas bearing blower; July 1944 - December 1944. DOE b(3)

Harris, Dr. Preston M. - DELETED

Herrick, Dr. Clifford E. Jr. DELETED

DOE b(3)

Hersey, Mayo D. - Consultant on general lubricating problems, bearing theory and patent matters concerned with the gas bearing blower;

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October 1943 - January 1945.

Hicks, Dr. John F. G. Jr. - Supervised research on corrosive properties of uranium hexafluoride, dynamic barrier plugging tests and on fluorocarbons; acted as liaison agent between SAM Laboratories and the K-25 Site; December 1943 - January 1945.

Hoard, Dr. James L. - Directed research at Cornell University on subcontract for measurement of the X-ray diffraction of uranium hexafluoride; July 1943 - June 1944.

Hull, Dr. Donald E. - Conducted research on the counting method of isotopic analysis; July 1942 - November 1943.

Hurley, Carl R. - Conducted research on process variables in DA barrier production and operated pilot plant for this purpose.

Inghram, Mark G. - Conducted research and development studies on mass spectrometer method for assay and analysis of plant gas mixtures and for isotopic abundances in uranium compounds.

Kaplan, Dr. Irving - Supervised principal theoretical and mathematical studies on plant design, operation and improvement.

Keeper, Dr. John S. - Conducted research on physical chemistry of uranium and fluorine compounds.

Knox, Dr. William J. - Conducted research on stabilization of barriers, consumption of process gas and corrosion problems.

Kraus, Dr. Charles A. - Consultant on problems of the inorganic chemistry of uranium compounds; October 1943 - December 1945.

Langsam, Dr. Robert T. - Conducted research on the development of methods for inert gas and separation factor testing of barriers; July 1942 - November 1943.

Lankau, Charles A. - Conducted research on slurry production and testing for the DA barrier pilot plant; September 1944 - January 1945.

Lassettre, Dr. Edwin N. -

DELETED

DOE b(3)

Lewinson, Victor A. -

Libby, Dr. W. F. - Directed work of all chemistry groups concerned with fundamental studies of stabilization and plugging of barriers, consumption of process gas by barrier and plant construction materials, and the development of new materials such as the fluorocarbons.

[redacted]

Long, Dr. Earl A. - Conducted research on the thermodynamic properties of uranium compounds; January 1942 - March 1943.

Lyon, Dr. Ashton M. - Conducted research on the development of MB barrier and the correlation of MB production data.

Mack, Dr. Edward, Jr. - Directed all research and development on the production of A barrier, including process control and pilot plant production; November 1943 - August 1944.

McMillan, Dr. William G. Jr. - Conducted research on effects of absorption of process gas on surfaces in the plant.

Melkonian, Edward N. -

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DoE b(3)

Menke, John R. - Conducted research on gas bearing blowers, blower bearings, theory of centrifugal compressors and the engineering development of pilot plants for isotope separation.

Miles, Dr. Francis T. - Supervised research on stabilization and plugging of barriers, and process gas consumption.

Miller, Dr. William T. - Supervised research on fluorocarbons and their development for use in the diffusion plant.

Moore, Dr. Walter J. Jr. - Conducted research on barrier stabilization and consumption; January 1943 - May 1944.

Murphy, Dr. George M. - Directed the administrative work of the Patent and Theoretical Groups and in addition was responsible for all technical reports including their editing, reproduction, distribution and custody.

Neubauer, Emil T. P. - Conducted research on the development and testing of seals for gas bearing blowers; March 1943 - April 1944.

Newman, Dr. Albert S. - Consultant on heat problems involved in the conditioning of barrier diffusers; July 1944 - September 1944.

Nierenberg, William A. - Conducted research on theoretical studies of cascades, single stage diffusion units and design of plants for isotope separation; experimental studies of mixing efficiencies and barrier separation efficiency.

Nix, Dr. Foster C. -

Norris, Edward O. -

DELETED

DoE b(3)

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Paxton, Dr. Hugh C. - Supervised research on isotope separation in single stage systems and on engineering tests of tubular diffusers and blowers; January 1943 - July 1944.

Pellissier, George E. Jr. - Conducted research on metallographic and electron microscope studies of structures of barriers and other materials of plant construction.

Pontius, Dr. Rex B. - Conducted research and development studies on methods for testing small samples of barrier materials for separating efficiency with uranium hexafluoride.

Priest, Homer F. - Conducted research on corrosion of plant materials and on the physical properties of uranium compounds; March 1941 - June 1944.

Roberts, Dr. Irving - Conducted research on correlation of inert gas testing methods used in plants with inert gas separation efficiencies measured in laboratory.

Romanoff, Frank P. -

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Roth, Dr. Walter L. - Conducted research on rates of corrosion..

Ruby, Dr. Willard R. -

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Scatchard, Dr. George - Supervised research on theory of gas flow through barriers; coordinated and interpreted experimental results on barrier theory; advised and planned new researches.

Urey, Dr. Harold C. - Sponsored or directed all research and development studies at the SAM Laboratories on the separation of uranium isotopes by the diffusion method under various government contracts with Columbia University; December 1941 - February 1945.

Vilbrandt, Dr. Frank C. -

DOE b(3)

Weidenbaum, Dr. Bernhardt -

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West, Dr. William - Conducted research on the behavior of barrier in the presence of flowing uranium hexafluoride; December 1942 - November 1943.

Williams, Dr. Clarke - Supervised research on spectrometric and other

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specialised analytical methods, high vacuum and other types of tests, and high vacuum pilot plant development research.

Williams, Dr. John W. -

[redacted]

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Willis, Alexander E.

[redacted]

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KEY PERSONNEL, BELL TELEPHONE LABORATORIES

Burns, Dr. R. M. - Supervisor and coordinator of all research and development for the Manhattan District at the Bell Telephone Laboratories.

Kohman, Dr. G. T. - Supervisor of corrosion, consumption and barrier plugging studies.

Mix, Dr. F. C. DELETED DOE b(3)

Schumacher, E. E. - Supervised metallurgical and microscopic studies on barrier materials.

White, A. H. DELETED DOE b(3)

KEY PERSONNEL, PRINCETON UNIVERSITY

Compton, Dr. C. H. - Coordinator of Princeton University barrier research activities.

Jeris, Dr. G. G. - Directed research work on barrier properties, and devised and supervised new experimental techniques.

Taylor, Dr. H. S. - Supervised and directed all research and development studies conducted for the Manhattan District at Princeton University on barrier production and use.

Turkevich, Dr. J. - In charge of optical studies and testing.

KEY PERSONNEL, KELLEX CORPORATION (RESEARCH ONLY)

Abbott, T. A. - Instrument Engineer. Participated in the development of several unique pressure, temperature and flow measuring and controlling devices.

Arnold, J. H. - Director of Kellex research and development. Supervised and coordinated all research and development studies and other technical phases of work under OSRD and Manhattan District contracts.

Baker, A. L. - Project Manager in charge of general administration and mechanical engineering - Manhattan District contract.

Benedict, Dr. M. - Engineer in charge of Process Design. Planned much of the experimental work on barriers, corrosion, pilot plant, cold traps, vacuum pumps and coolers under OSRD and Manhattan District contracts. Carried out all the fundamental mathematical studies of the diffusion process and established the basic principles upon which the design of the plant is founded. Also developed the process design for the entire plant and auxiliaries excepting utilities.

Kisser, Dr. H. M. - Consultant Chemist. Critically reviewed essentially all phases of the research and development work; aided in setting of specifications and procedures for large scale manufacture of special materials and continually inspected and constructively criticised chemical aspects of such manufacturing units and of the large diffusion plant.

Hobbs, J. C. - Consultant Mechanical Engineer. Developed a complete line of valves of unique design for vacuum service. Developed special expansion joint and designed several models of small scale diffusion units. Also consulted on a variety of other development problems.

Hopkins, W. A. - Engineer in charge of cleaning. Supervised development of and application of cleaning methods. Also supervised development work on nickel plating.

Jacobs, Dr. R. B. - Physicist. Developed vacuum testing techniques and special vacuum equipment under OSRD and later under Manhattan District contracts.

Johnson, Dr. C. A. - Research Engineer. Developed barrier eventually used in plant. Also supervised much of the experimental work on corrosion, pilot plant, cold traps and cooler under OSRD and Manhattan District contracts. He also supervised equipment development tests in conjunction with large plant operation.

Keith, P. C. - Vice President and Executive in Charge of the Kellex

Project. Formerly member of Planning Board of OSRD Project SSRC-17. Directed considerable early research and development as well as other technical work under Manhattan District contract.

Nier, Dr. A. O. C. - Physicist. Did early work on mass spectrometer at University of Minnesota. Continued work at Kellex under Manhattan District. Responsible for mass spectrometers used for leak detection analysis of contaminants in plant process stream and isotopic analysis as well as for a variety of other applications. Also developed numerous other analytical machines and tools.

Powers, R. E. - Conditioning Engineer. Critically reviewed the research and development work on cleaning and conditioning. Applied the results to the design of large scale equipment, supervised the performance tests on this equipment and directed all subsequent development work on cleaning and conditioning techniques.

Rose, H. A. - Developed two types of vacuum pump, mist filters, etc. for pumping process gases of large plant. Consulted on vacuum testing and conditioning problems.

Rosen, Dr. R. - Chemist in charge of special chemicals. Devised inspection methods and compiled specifications for all special chemicals developed for the large plant. Also carried out a variety of chemical investigations including the bulk of the work on valve seats.

Schumann, Dr. S. C. - Research Chemist. Supervised the later work on corrosion, carbon traps and valves and the work on cold traps and vacuum pumps.

Skau, L. - Engineer in charge of mechanical engineering. Developed special power generating and distribution systems for large plant. Also supervised mechanical engineering development of diffusers and other special process equipment.

Squires, A. M. - Process Engineer. Aided in the mathematical studies on the fundamentals of the diffusion process and on the productivity, equilibrium time and preferred modes of operation of the large diffusion plant. Also aided in the development of the process design of the main plant equipment.

Stoddard, W. B. Jr. - DELETED DoE)b(3)

Swearingen, Dr. J. S. - Engineer in charge of pump development. Developed the pump seal used in Allis-Chalmers and Elliott models carrying out incidental work under OSRD and later work under Manhattan District. Also did fundamental work on pump designs and gas bearings. Also developed test methods and apparatus.

Taylor, H. S. - Consultant Physical Chemist. Coordinated later work on

barrier development of both Kellex and SAM Laboratories which led to the product eventually used in plant.

Watts, G. H. - Engineer in charge of pump department. Supervised all development work on special process pumps including Allis-Chalmers, Valley Iron and Elliott models. Also supervised performance tests at factory and plant.

KEY PERSONNEL, INTERCHEMICAL CORPORATION

Fullam, E. F. - Developed methods for accurate size determinations on metal powders; also sectioning methods and techniques for electron microscope examination of the interior and surface of barriers.

Gans, Dr. D. M. - Assisted with supervision and coordination of all research and development studies for the District at the Research Laboratories of the Interchemical Corporation.

Gessler, Dr. A. M. - Supervised and coordinated all research and development studies conducted for the Manhattan District at the Research Laboratories of the Interchemical Corporation.

Green, M. - Supervised microscopic work in connection with research on metal powders.

KEY PERSONNEL, CALIFORNIA INSTITUTE OF TECHNOLOGY

Badger, Dr. R. M. - Supervised and coordinated all research conducted at the California Institute of Technology. Originated and developed methods for the study of barrier material.

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Campbell, Dr. D. - Consultant on the determination of pore size in barriers by use of graded colloidal particles.

Epstein, Dr. P. S. - Consultant on theoretical matters relating to barriers.

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